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MDCCCXV.

ADVERTISEMENT.

THE Committee appointed by the *Royal Society* to direct the publication of the *Philosophical Transactions*, take this opportunity to acquaint the Public, that it fully appears, as well from the council-books and journals of the Society, as from repeated declarations which have been made in several former *Transactions*, that the printing of them was always, from time to time, the single act of the respective Secretaries, till the Forty-seventh Volume: the Society, as a Body, never interesting themselves any further in their publication, than by occasionally recommending the revival of them to some of their Secretaries, when, from the particular circumstances of their affairs, the *Transactions* had happened for any length of time to be intermitted. And this seems principally to have been done with a view to satisfy the Public, that their usual meetings were then continued, for the improvement of knowledge, and benefit of mankind, the great ends of their first institution by the Royal Charters, and which they have ever since steadily pursued.

But the Society being of late years greatly enlarged, and their communications more numerous, it was thought advisable that a Committee of their members should be appointed, to reconsider the papers read before them, and select out of them such as they should judge most proper for publication in the future *Transactions*; which was accordingly done upon the 26th of March, 1752. And the grounds of their choice are, and will continue to

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be, the importance and singularity of the subjects, or the advantageous manner of treating them; without pretending to answer for the certainty of the facts, or propriety of the reasonings, contained in the several papers so published, which must still rest on the credit or judgment of their respective authors.

It is likewise necessary on this occasion to remark, that it is an established rule of the Society, to which they will always adhere, never to give their opinion, as a Body, upon any subject, either of Nature or Art, that comes before them. And therefore the thanks which are frequently proposed from the Chair, to be given to the authors of such papers as are read at their accustomed meetings, or to the persons through whose hands they receive them, are to be considered in no other light than as a matter of civility, in return for the respect shewn to the Society by those communications. The like also is to be said with regard to the several projects, inventions, and curiosities of various kinds, which are often exhibited to the Society; the authors whereof, or those who exhibit them, frequently take the liberty to report, and even to certify in the public newspapers, that they have met with the highest applause and approbation. And therefore it is hoped, that no regard will hereafter be paid to such reports and public notices; which in some instances have been too lightly credited, to the dishonour of the Society.

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The PRESIDENT and COUNCIL of the ROYAL SOCIETY adjudged the Medal on Sir GODFREY COPLEY's Donation, for the year 1814, to JAMES IVORY, Esq. for his various Mathematical Communications, printed in the Philosophical Transactions.

The Parsonian and Copleian of the Royal Society adjudged the Medal on Sir Godfrey Copley's Donation, for the year 1814, to James Ivory, Esq. for his various Mathematical Communications, printed in the Philosophical Transactions.

PHILOSOPHICAL TRANSACTIONS.

I. *Additional observations on the optical properties and structure of heated glass and unannealed glass drops.* By David Brewster, *LL. D. F. R. S. Edin. and F. S. A. Edin. In a Letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. K. B. P. R. S.*

Read November 10, 1814.

DEAR SIR,

Edinburgh, April 8, 1814.

IN a former paper on the optical properties of heated glass and unannealed glass drops, I have briefly described the leading phenomena which they exhibit in their action upon polarised light. These experiments I have frequently repeated with the same results, and I have the satisfaction also of stating, that as soon as they were known in France, they were repeated and verified by M. BIOT of the National Institute, to whose active genius this branch of optics owes great obligations.

Having ascertained that glass melted and suddenly cooled, possessed all the optical properties of crystallized bodies, I was anxious to determine if it exhibited any other marks of

a crystalline structure. Upon examining the bulb of an unannealed drop AB, Pl. I., fig. 1, by holding it between the eye and a sheet of white paper, I observed a number of lines converging to the vertex *a*, as represented in fig. 2. This structure was more or less apparent in every bulb which I examined, but never appeared in annealed drops. It exhibited itself even on the surface, and seemed to be owing to an imperfect crystalline form, yet it was not marked with sufficient distinctness to entitle me to consider it as the effect of crystallization. In one specimen, however, where the bulb AB remained unshattered, while all the rest of the drop was burst in pieces, the lines diverging from *a* were most distinctly marked, and the bulb was actually cleft in the direction of these lines, so as to produce a real dislocation at the *surface* of the drop. We may therefore consider the drop as possessing that crystalline structure which gives cleavages in the direction of lines dive its apex. By examining the fragments of t is burst, another cleavage is distinctly per ptible: it is parallel to the outer surface, and produces a concentric structure like that of an onion. This cleavage also shows itself in the splinters which are detached from the surface of the drop when it is ground upon freestone. A third cleavage is visible in the direction of lines inclined to the axis of the drop, as represented in fig. 3; but it is not so distinct as the two first.

As it appeared probable that the glass drops possessed a less degree of density than if they had been annealed, I attempted to ascertain this point by measuring their specific gravities in these two different states. The unannealed drops, however, had always one or more vacuities, such as E, F,

fig. 1, so that I was able to obtain only approximate results by estimating the magnitude of these cavities.

The following specific gravities were measured by my friend Mr. JARDINE, with his usual correctness.

Unannealed flint glass drop, fig. 1, -	3.20405
Annealed flint glass from the same pot	3.2763

In order to correct the first of these measures, I moulded a piece of bees' wax into the size and form of the cavities E, F, fig. 1, by examining them under a fluid of the same refractive power as the glass. I then formed the two pieces of wax into a sphere, and thus ascertained, with tolerable accuracy, the weight of a quantity of water of the same magnitude as the cavities. By this means I obtained the following measure,

Corrected specific gravity of the unannealed drop 3.264, a result differing so little from that of the annealed glass, that we may consider them as having nearly the same density.

With the view of obtaining some farther insight into the structure of the crystallized drop, I brought the one, represented in fig. 1, nearly to a red heat. Its shape suffered no change at this temperature, and the vacuities E, F, still remained; but it had now lost the faculty of depolarisation, and the particles had therefore assumed a new arrangement. By increasing the temperature, the cavities E, F, disappeared: the lower side of the drop, upon which it rested, was indented by the bottom of the crucible; but it had in no other respect lost its external shape, the appearance of the cleavage in fig. 2 remaining unaltered. In this state Mr. JARDINE measured the specific gravity of the drop, and found it to be 3.278, which is almost exactly the same as that of the annealed drop.

In order to observe the manner in which the cavities disappeared, I suspended one of the drops by a wire, and viewed it with a telescopic microscope when exposed to a strong heat. Soon after the drop became red hot, the cavities gradually contracted, and at last vanished, the centre of the cavity being the part that was last filled up. The drop had begun to melt at its smaller extremity, but the lines represented in fig. 2 were still visible, the heat probably not having been sufficiently intense to affect its superficial structure.

As the specific gravity of the crystallized drop is nearly the same as that of the annealed drop, the cavities must be produced by the contraction which the internal part experiences in cooling, for the sudden induration of the outer layer prevents the contraction from taking place in any other way. The manner, too, in which the cavities disappear, is a complete proof that they contain no air, and hence we may consider their magnitude, which increases with the size of the drop, as a measure of the contraction which the glass undergoes in its transition from the temperature at which it melts, to the ordinary temperature of the atmosphere.*

I am informed by Dr. HOPE, that he has frequently obtained unannealed drops of crown glass, in which there were no vacuities, and that they all burst spontaneously in the course of a few months. As there is at present no crown glass manufactory in this part of Scotland, I have not been able to make any experiments with drops of this kind; but there is every reason to believe that they would exhibit the same optical properties, as those which are formed of flint

* Upon this supposition, the contraction of glass in bulk, in passing from the first of these states to the second, will be $\frac{1}{44.9}$ or 0.02205.

and bottle glass; and that the contraction of the internal parts, in consequence of which the vacuities are produced, is not necessary to that arrangement of particles upon which these properties depend. In the flint glass drops, such as ABC, fig. 1, there is sometimes only one vacuity, in the thick part at E, and as the slender extremity C is perfectly cold before the vacuity E is formed, and when the glass round E is red hot, it is obvious that the part C has suffered no contraction, and is in the same state as the crown glass drops obtained by Dr. Hope. But the extremity C has a more perfect structure than the bulb AB, as it possesses distinct neutral axes: hence we may infer that the crown glass drops, without vacuities, will exhibit neutral axes in every part of their length; that their structure is more uniform than that of flint and bottle glass drops; and that the difference between the specific gravity of the drop, and that of the annealed crown glass from which it is made, will afford a correct measure of the contraction which the glass experiences, in passing, by a gentle gradation of temperature, from the fluid to the solid state.*

* When a piece of red hot steel is plunged in cold water, it experiences a diminution of density analogous to that which takes place in drops of melted crown glass. Mr. R. Pennington found that a piece of steel, which, when soft, measured 2.769 inches had expanded to 2.7785 inches, after being hardened by immersion, when red hot, into cold water. Mr. Cavallo gives the following measures, without mentioning by whom the experiment was made.

Specific gravity of soft steel hammered - - 7.840
——————— of soft steel hammered, and hardened in water 7.818.

In all these cases the particles are held in a state of unnatural constraint by the sudden induration of the external coat; and therefore it is probable, that neither the glass nor the steel will expand by any moderate accession of temperature. If this conjecture be well founded, it will enable us to supply one of the greatest desiderata in the arts, a *pendulum of invariable length*.

The contraction of the flint glass drops, as computed from the magnitude of the cavities, must always err in defect; but the maximum result obtained from a considerable number of drops may be regarded as a tolerably correct measure of the diminution of density.* For this purpose, those drops should be employed in which the cavities are numerous, and scattered over every part of their length. The largest drops have generally this character, and I have one of these in my possession, in which there are no fewer than *seven* cavities.

A considerable degree of difficulty is experienced in procuring unannealed drops of flint glass. Owing, I presume, to the softness of this kind of glass, the greater number of the drops burst as soon as they are cooled, and from some pots of glass I have been able to procure only four drops out of twenty-four that were plunged into the water. One of these burst in my hand some hours after it was made, without any part of the tail having been previously broken, and another burst on the following day when lying on the table exposed to no change of temperature. The best method of obtaining the drops entire, is to watch the moment when the red heat disappears in the centre of the bulb, and to remove it instantly from the water.

As the minutest fragments of all crystallized bodies have the same action upon light, as the crystals of which they formed a part, I expected a similar property in the fragments

* The specific gravity of the unannealed drop, as corrected in page 3, from an estimate of the size of the cavities, approaches very near to that of the annealed drop. The difference is only 0.012, and would have been considerably less had the cavities been more numerous.

of the shattered drops. One of these, which was about the sixtieth of an inch thick, did not possess the property of depolarisation, and with more than twelve fragments of different thicknesses, below the thirtieth of an inch, I obtained a similar result. A fragment, however, of a crown glass tear, which had burst after being dropped into the water, and which was about two-tenths of an inch thick, depolarised light in every position, but did not exhibit any coloured rings by polarised light.

I have not been able to make a complete series of experiments on the effects of heat upon crystallized bodies, but it will appear from the following experiment that they are not likely to conduct us to new results. I heated to a great degree a fine crystal of spinelle ruby, which has not the property of double refraction, but it did not produce the least change upon a polarised ray. The crystal was $\frac{1}{18}$ of an inch thick; and a piece of crown glass of the same thickness, and brought to the same temperature, depolarised a considerable portion of light.

The effects of heat, as indicated by the preceding experiments, are, perhaps, too imperfectly developed to authorise us to draw those important conclusions, to which they seem so well calculated to conduct us. One of these, however, is so palpable, and so clearly deducible from the phenomena, that it must already have suggested itself, namely, the production of a *new species of crystallization* by the agency of heat alone. When light is transmitted perpendicularly through a plate of glass, the glass exercises no more action upon it, than if it were a mass of water. When the glass, however, is heated, the particles not only expand, but assume a new arrange-

ment, till at a certain temperature the crystallization is complete. As the temperature diminishes, the particles approach one another, and gradually recover their former arrangement. The crystallization which is thus produced in drops of melted glass, is rendered permanent by the sudden immersion of the drop in water, which arrests the particles in that particular position that constitutes the crystalline state of the body. Hence it follows that the particles of glass, when separated to a certain distance by the expansive energy of heat, assume a crystalline arrangement; and, unless they are fixed in this state, by a sudden diminution of temperature, the crystallization is gradually destroyed by the approximation of the particles which takes place during the operation of slow cooling.

During my experiments on depolarisation, which I shall soon have the honour of submitting to your notice, I discovered another species of crystallization, which is the effect of time alone, and which is produced by the slow action of corpuscular forces. This kind of crystallization appears, in general, to accompany the consolidation of many vegetable and animal products, and will probably be found to have had an extensive influence in those vast arrangements which must have attended the formation of our globe.

I have the honour to be,

Dear Sir,

your most obedient humble servant,

DAVID BREWSTER.

To the Right Hon. Sir JOSEPH BANKS, Bart. K. B. P. R.S.

Fig. 1.

Fig. 2.

Fig. 3.

II. *Description of a new instrument for performing mechanically the involution and evolution of numbers.* *By* Peter M. Roget, *M. D. Communicated by* William Hyde Wollaston, *M. D. Sec. R. S.*

Read November 17, 1814.

To abridge that species of mental labour which is required in conducting arithmetical computations, has been the professed object of a variety of mechanical contrivances. But the greater number of arithmetical machines, as they have been called, are more ingenious than really useful, and have been recorded more as objects of curiosity, than as admitting of convenient or ready application in the actual practice of arithmetic. The machine invented by Pascal, and others constructed on the same principle, were, strictly speaking, limited to the simpler operations of addition and subtraction, and were incapable of being applied to the finding of products or quotients in any other way than by effecting a number of successive additions or subtractions. Still less did they aim at the immediate performance of the higher operations of involution, which, even by the most compendious methods of arithmetic, is a laborious process; or of the extraction of roots, to which the common rules furnish but a circuitous and slow approximation.

The only instruments which promise to afford real assistance to the practical calculator, are those founded on the theory of logarithms: a theory, which has been the fertile

source, as well as the commodious instrument of discovery in every department of mathematical inquiry. The scale of GUNTER, and the common sliding-rule, are derived from the properties of logarithms; and the purposes to which they are immediately applicable are the *multiplication* and *division* of numbers. The instrument, of which I purpose giving an account to the Society in this communication, is founded on a particular mode of employing logarithms, and is calculated to apply immediately to the *involution* and *evolution* of numbers. To those who are already conversant with mathematical pursuits, a few words would suffice to explain the principle on which it operates: but to such as are not familiar with the practical employment of logarithms, or of the common sliding-rule, the following statement of the chain of reasoning on which they depend, may conduce to render the subsequent details more intelligible.

The mode in which logarithms are instrumental in facilitating computation, is by converting the more difficult and laborious into the simpler operations of arithmetic. This is effected by substituting, instead of the numbers on which the requisite operations are to be performed, other numbers previously calculated and arranged in tables, so that every number in the natural series, has one of these artificial numbers, or logarithms, corresponding to it. These logarithms are so calculated, that, by adding together those which correspond to any given factors, the sum obtained shall be the logarithm, or artificial number, corresponding to the product of these factors. By consulting the tables, therefore, this product may be discovered; for it will be the number answering to the logarithm, or sum, thus obtained. The

subtraction of one logarithm from another will, in like manner, give the logarithm of the quotient resulting from the division of the number corresponding with the second, by the number corresponding with the first. The multiplication of a logarithm by any number will change it into another logarithm, which will answer to that power of the number corresponding with the former logarithm, which has this multiplier for its exponent.

But it will be seen that even in the simplest and most direct applications of this invention some exertion of arithmetical skill and some share of mathematical knowledge are requisite. Even this species of labour may, however, be avoided by the employment of lines as the representatives of logarithms; so that by the simple admeasurement of these lines, with their sums, differences, or multiples, on a given scale, the result of any of the above mentioned operations may be obtained within a certain degree of accuracy. A farther improvement consists in graduating a line of a convenient length *logometrically*, that is, dividing it so that the distance of each division from the beginning of the line, which is marked with unity, shall measure, on a given scale of equal parts, the logarithm of the number which is affixed to it. A line so divided is known by the name of GUNTER's scale.

The divisions which are situated at equal distances, being marked by numbers whose logarithms have equal differences, it follows that the spaces intervening between any two numbers are proportional to the differences between their respective logarithms; or are measures of the ratios between each of these numbers. The same use may therefore be made of such a scale, as of a table of logarithms with regard to operations to

be performed on their corresponding numbers. Thus it will be found, that the portion of the scale extending from 1 to 3, added to that extending from 1 to 4, is equal to that between 1 and 12: showing that the logarithm of 3, added to that of 4, is equal to the logarithm of 12: or that the ratio of 1 to 3, added to that of 1 to 4, composes the ratio of 1 to 12: or that 12 is the product of 3 and 4. The excess of the interval between 1 and 24, over that between 1 and 6, or, what is the same thing, the interval between 6 and 24, will be equal to that between 1 and 4; showing, by a similar process of reasoning, that 4 is the quotient of 24 divided by 6. This comparison of the intervals between the numbers on GUNTER's scale is effected with great ease by the addition of another scale, which may be called the slider, exactly equal in length to the former, and bearing the same divisions, but capable of being moved by its side, so as to allow of any part of the one being applied to any part of the other. In this form it constitutes the common sliding-rule, the utility of which is so generally known in resolving all questions that require the simple operations of multiplication and division, or relate to the finding of any term of a proportion. Supposing the two scales originally to coincide, the sliding scale being the undermost, by advancing the slider any given distance, each of its divisions will be brought under those of the fixed scale, which before were respectively situated farther forwards by an interval equal to that given distance. Every number in the upper scale will therefore have to the number standing under it on the slider, the same constant ratio; a ratio indicated by the number under which the unity, or commencement of the scale, of the slider has been placed. The former

numbers will therefore be the multiples of the latter by this constant number. Thus, by adjusting the slider, so that its unity shall stand under any given multiplier or divisor, the upper line will exhibit the series of the products of all the subjacent numbers by the given multiplier: and conversely, the slider will exhibit the series of the quotients resulting from the division of the numbers immediately above them by the given divisor.*

* As the practical mode of using the sliding-rule is frequently not obvious even to those who are in possession of the principle of its construction, I shall beg leave to point out the following proposition, as one that leads directly to the solution of every case to which the instrument can be applied, and an attention to which, therefore, may conduce to its more ready and more general employment. *In every position of the slider, all the fractions formed by taking the numbers on the upper line as numerators, and those immediately under them as denominators, are equal.* Thus every corresponding numerator and denominator, having to each other the same ratio, may be considered as two terms of a proportion. Any two of these equivalent fractions will therefore furnish the four terms of a proportion; of which any unknown term may be supplied, when the others are given, by moving the slider till the numbers composing the terms of the given fraction, are brought to coincide on the two lines. The required term will then be found occupying its proper place opposite to the other given term. Thus, from the proportion A : B :: C : D, we may derive $\frac{A}{B} = \frac{C}{D}$; and adjusting the slider so that B shall stand under A, D will be found under C, when C is given: or C will be found over D, when D is given. A similar process would have furnished A or B, when one of them together with C and D, were given. Since the products of each numerator by the denominator of the other fraction are equal; (that is, AD = BC); when one of the terms is unity, the question becomes one of simple multiplication or division. The product of A and B, which we may call P, will be found, as before, by placing the slider so as to express the fractions $\frac{A}{1} = \frac{P}{B}$. The quotient of A divided by B, which we may call Q, will in like manner be found by forming the fractions $\frac{A}{B} = \frac{Q}{1}$: that is, in the former case, the product P will stand over B, when the 1 on the slider is brought under A; and in the latter case, the quotient Q will stand over the 1 of the slider when B is brought under A.

This instrument has been variously modified with a view of enlarging its scale, or of adapting it to particular objects, such as the calculation of exchanges, the measuring of plane and solid bodies, and the computations of trigonometry. The Society has recently witnessed its successful application, by Dr. WOLLASTON, to another science, in his synoptic scale of chemical equivalents, for the invention of which every practical as well as philosophical chemist must acknowledge to him their deep obligation.

But to whatever purposes the sliding-rule may have been applied, its use is necessarily limited to those operations which are performed by the simple addition or subtraction of logarithms, and to the corresponding arithmetical operations above mentioned. It is not directly adapted to the multiplication or division of logarithms by any number, and therefore is not directly calculated to perform the involution or evolution of numbers, to which, as was before noticed, the multiplication and division of logarithms correspond. Yet many practical, as well as philosophical, inquiries occur, in which it is necessary to ascertain the powers and roots of numbers. In all researches, for example, which involve geometrical progressions, or exponential quantities, and whenever the terms of a series are to be computed in obtaining approximate solutions, these questions present themselves. The common sliding-rule furnishes no direct mode of determining even the simple power or root of a given number: and when the exponent of the required power or root is not an integral, but a fractional number, its inadequacy to resolve the question is still more apparent. The squares and square roots, it is true, are often pointed out on the common rules, by means of a supplemen-

tary line graduated so that each of its divisions are double in length to those of the two other lines. A line of cubes, or cube roots, or of any other given power, might, in like manner be subjoined. But it is obvious that the uses of any such additional lines are confined to cases where a particular power is concerned: they give us no assistance in the case of any other power or root, which has no immediate relation with the former.

A new mode of graduation has occurred to me which possesses these requisites, and exhibits, on simple inspection, all the powers and roots of any given number, to any given exponent, with the same facility, and in the same way, that products, quotients, and proportionals, are exhibited by the common sliding-rule. It is accordingly a measure of powers, in the same way as the scale of GUNTER is a measure of ratios. An example will best illustrate the principle of its construction. If it were required to raise the number 2.123 to the fifth power: availing ourselves of logarithms, we should multiply the logarithm of 2.123 (or 0.32695) by 5. The product (1.63475) would be found by the tables to correspond to 43.127, which, with decimals to three places only, is the number required, or the fifth power of 2.123. If the exponent, instead of an entire number, as 5, were fractional, as 4.3719, the operation of multiplying by such a number would be more tedious, and might evidently again be abridged by having recourse to logarithms. Taking, then, the logarithm

of - - -	0.32695 or 9.5144813
and the logarithm of -	4.8719 or 0.6406702
and adding them, we obtain -	0.1551525

a logarithm answering to the number 1.4294, the product we have been seeking. But this product is itself a logarithm, namely, the logarithm of the power required. The number having for its logarithm 1.4294, namely, 26.878, is therefore the power sought for, or 2.193^{+3719}.

It may be observed, in this last example, that of the numbers added together, the first was the logometric logarithm, (that is, the logarithm of the logarithm) of the given root: the second was the simple logarithm of the exponent; and the sum of these was the logometric logarithm of the power. If, therefore, we were at the pains to construct a table having three sets of columns; the first containing the natural series of numbers; the second, their corresponding logarithms; and the third, containing the logarithms of those logarithms; we should possess the means of raising any given number to any given power, by the simple addition of the numbers in the second and third columns; just as common multiplications are effected by the addition of common logarithms. It is evident that a line might be graduated so that its divisions should correspond to the numbers in the third column, or should represent the logometric logarithms of the numbers marked upon them: and if this line were applied so as to slide against another line logometrically divided, it would enable us to effect the very operation I have been describing, and thus give us, by inspection, the powers corresponding to any given root and exponent.

The instrument, then, in its simplest form, would consist of two graduated scales applied to each other. A portion of these scales is represented, Pl. II, fig. 1. The lower rule, AA, which I shall call the slider, is the common GUNTER's

double line of numbers, or is a line logometrically divided; the divisions of the first half being from 1 to 10, and being repeated on the second half in the same order. The upper or fixed rule, BB, is graduated in such a manner, that each of its other divisions is set against its respective logarithm on the slider; and, consequently, all the numbers on the slider will be situated immediately under those numbers in the upper rule, of which they are the logarithms. Thus 2 on the rule will be over 0.30103 of the slider; 3 over 0.47712: 2 on the slider will stand under 100 on the rule; 8 under 1000; and so on.

As the series of ordinary logarithms express the exponents of 10, of which the corresponding numbers are so many successive powers, it is evident that, in this position of the instrument, the upper line will exhibit the series of the powers of 10, corresponding to all the exponents marked on the slider. It will be seen, for instance, that the second power of 10 is 100, the third, 1000, &c.: that the 0.5th (or the square root) is 3.163; the 0.25th (or the fourth root) is 1.778; the 0.2th (or the fifth root) is 1.585: and so on.

In every other position of the slider, the upper rule will exhibit, in like manner, the series of powers of that number under which the unit of the slider has been placed, while the opposite numbers on the slider are the exponents of those powers. Thus, if (as in Pl. II, fig. 2) the unit of the slider be placed under the division 3 of the upper rule (at R); the square of 3, or 9, will be found over the 2 of the slider: its cube, 27, over the 3; its fourth power, 81, over the 4: and so on for any other power. It is evident, then, that in order to find a given power of any number, the unit of the slider

must be set underneath that number in the upper rule; and that the number sought will then be found above that number in the slider which expresses the magnitude of the required power.

Such being the mode of its application to the finding of powers, its use will be obvious in performing the contrary operation of finding roots. The root might, for this purpose, be considered as a fractional power: but as this would require a reduction to decimals, the easiest mode will be to place the number expressing the degree of the required root under the given number, and the root itself will then be found over the unit, or beginning of the scale, in the slider. For fractional powers, the denominator of the exponent must be placed under the root, and its numerator will then point out the power.

It is hardly necessary to add, that by the same mode we may discover the exponent of any given power to any given root: since, whatever be the root over the unit of the slider, the whole series of the powers of that root, with their corresponding exponents, are rendered apparent. This circumstance may indeed be considered as an additional recommendation to the employment of this instrument: for it affords to those less versed in the contemplation of numerical relations an ocular illustration of the theory of involution. It presents, at one view, the whole series of powers arising from the successive multiplication of all possible numbers, whether entire or fractional; and exhibits this series in all its continuity when the exponents are fractional, and even incommensurate with the root itself. The production of the upper line in one direction conveys a more accurate notion of the pro-

gressive and rapid increase of those powers, than can be acquired by mere abstract reflection: and its continuation on the other side, shows the slow approximation to unity which takes place in the successive extractions of higher and higher roots.

A variety of forms of construction might be given to instruments operating on the principle now explained. The following has appeared to me, on the whole, to be the most convenient for practical purposes; it is represented on a reduced scale in Pl. II, fig. 3. In order to preserve a sufficient magnitude of scale, I have divided the line of roots and powers into two parts; placing the one above and the other below, and interposing a slider with a double scale of exponents. The slider of the common sliding-rule is graduated in a way that is exceedingly well suited to this purpose, having divisions on each edge, and carrying two sets of numbers from 1 to 10. Adapting a blank ruler to one of these sliders, which must be fixed in a proper position, I mark off, on the upper line, the series of numbers against their respective logarithms on the slider; placing 10 over the middle unit of the slider, 100 over the 2, 1000 over the 3, and so on, proceeding towards the right from 10 to 10000000000, the tenth power of 10, an extent which is more than sufficient for all useful purposes. The space to the left is also graduated on the same principle, from 10 to 1.259 which is the tenth root of 10, or $10^{0.1}$. The upper portion of the rule being thus filled, I place the continuation of the same line on the lower portion, beginning on the right hand, and proceeding in a descending series of fractional powers of 10, corresponding with the exponents on the intermediate slider, which, when applied to this portion, are to be taken as only

one hundredth of their value when applied to the upper portion. While 1.259 therefore is marked on the right, 1.02335 ($= 10^{0.01}$) will occupy the middle, and 1.002305 ($= 10^{0.001}$) the left end of the lower line. It is evident that the graduation might thus be continued indefinitely in both directions. But for all practical purposes the limits thus obtained will be found amply sufficient: for the well known property of the logarithms of roots in a descending series, enables us to dispense with all farther continuation of the scale in that direction. In proportion as numbers in a descending series approach very near to unity, their logarithms bear more and more exactly a constant ratio to the excess of those numbers above unity, namely, the ratio expressed by the modulus of the system, or 1 to .4342944819, &c. As we descend in the scale, therefore, the decimal part of the exponents becoming smaller and smaller, the corresponding logarithms will approximate so nearly to the multiple of that decimal part by this modulus, that no *sensible* error will result from assuming them to be the same.* The divisions to the left of the lower portion of the rule may therefore be taken as sufficiently accurate representations of the divisions which would occur in the succeeding portions of the line, if it were prolonged indefinitely in that direction.

The applications of which this instrument is susceptible are

* Thus the logarithm of 1.05 is .021189
that of 1.005 is .0021661
and of 1.0005 is .00021709
which differs from the product of the modulus by .0005 (or .00021715) by a quantity affecting only the fourth significant figure. The roots 1.0005, 1.00005, 1.000005, &c. may, therefore, without sensible error, be considered as coinciding with the division 217 on the slider.

various, and will easily present themselves. In many speculative and practical inquiries, cases occur in which geometrical progressions are concerned, and in which it becomes a question, the first term and the common ratio being given, to find the other terms; or, knowing the first and also any other term, to ascertain the rate of increase. In all these cases, it is obvious that the first term is to be regarded as the root, or first power, and the unit in the slider adjusted, so as to coincide with that number in the line of powers, that is, in the upper and lower portions of the fixed rule. The number of terms will constitute the exponent of the series, and the power corresponding to each successive exponent 2, 3, 4, &c. will be the second, third, fourth, &c. term of the progression.

The successive amounts of a sum placed at compound interest compose a geometrical progression; and accordingly all questions of compound interest are resolvable by this instrument. The rate of interest, or the per centage per annum, being added to 1, gives the amount of £1. at the end of one year. Thus, at 5 per cent. the amount is 1.05, at 3 per cent. 1.03, and so on. In either case this number is to be regarded as the first term, or root of the series. Setting the unit of the slider against this number on the rule, we shall find the amount of £1. at the end of $5\frac{1}{2}$ years, opposite to the number 5.5 on the slider, and the same of any other interval of time. If it be required to ascertain in what time a sum placed at compound interest at 3 per cent. would be doubled: placing the unit over 1.03, the number 2 on the rule will indicate 23.45 on the slider, as the number of years required for doubling the sum at that rate of compound interest.

Questions relating to the increase of population and to the

calculation of chances, involve the investigation of powers, which may be facilitated by this instrument. Examples of its application also occur in considering the reduction of temperature which bodies undergo by the communication of heat to surrounding bodies, the quantities of light transmitted through different thicknesses of a transparent medium: the diminution of density which the air in a receiver undergoes during its exhaustion by the air pump, and the relation of the density of the atmosphere with its elevation. The interpolation of a given number of mean proportionals between two given numbers, is sometimes required for the solution of a problem, and is easily effected by the rule above described. Thus, in dividing the musical octave into twelve equal semi-tones, the following series of numbers must be calculated, viz. $2^{\frac{1}{12}}$, $2^{\frac{2}{12}}$, $2^{\frac{3}{12}}$, $2^{\frac{4}{12}}$, $2^{\frac{5}{12}}$, $2^{\frac{6}{12}}$, $2^{\frac{7}{12}}$, $2^{\frac{8}{12}}$, $2^{\frac{9}{12}}$, $2^{\frac{10}{12}}$, $2^{\frac{11}{12}}$: this can readily be done in one position of the slider, for when the 12 marked on it is placed under 2 on the rule, the 1 of the slider will point to $1.0595 = 2^{\frac{1}{12}}$, the 2 of the slider will indicate $1.1225 = 2^{\frac{2}{12}}$, the 3, $1.1892 = 2^{\frac{3}{12}}$, &c.

When the first term of a progression is less than unity, all the succeeding terms, that is, all the powers of that fraction, continually decrease. Now all the numbers contained on the rule are above unity: but the terms of such a decreasing progression may yet readily be found by assuming, instead of the first term, its reciprocal, which, being above unity, will of course be contained on the scale. The powers of this reciprocal, will, in like manner, be the reciprocals of the required series, which will accordingly be determined without difficulty. Let the following question, for example, be proposed.

Assuming, that when light is transmitted through water, one half of the quantity that entered is lost by passing through seven feet of water:* how much will be intercepted by passing through three feet? In questions of this sort it must be recollected that it is the quantities of transmitted, and not of intercepted light, that are in geometrical progression. If 0.5 is transmitted by seven feet, $0.5^{\frac{3}{7}}$ will be transmitted by three feet. As 0.5 is not contained on the rule, we must take its reciprocal 2, of which the $\frac{3}{7}$th power, or 1.3023, is given by the instrument: this number being opposite to the 8 on the slider, when its division 7 is placed under 2 on the rule. The reciprocal of 1.3023 or .9892 is the quantity transmitted; and therefore .0108 the quantity absorbed by three feet of water.

A variety of propositions relating to the general theory of logarithms are illustrated by this instrument. The assumption of the number 10, as the basis of our system of logarithms is arbitrary, and is chosen only for the sake of greater convenience in computation. The hyperbolic system, which has the number 2.302585093, &c. for its basis, possesses other advantages, especially in the higher branches of analysis. The instrument may be made to exhibit at one view the series of any particular system of logarithms, that is, of a system with any given basis, or any given modulus, by merely setting the unity of the slider against the given basis on the rule: or the given modulus on the slider against the number 2.7182818, &c. on the rule. The divisions on the slider will then denote the logarithms of the numbers opposed to them on the rule.

* Young's Lectures on Natural Philosophy, I. 409.

Let it be required to determine the particular system of logarithms, in which the modulus shall be equal to the basis. Take out the slider, and introduce it in an inverted position, so that the numbers on it shall increase from right to left: and place the number .4343, &c. (the modulus of the common system) under 10 (its corresponding basis) on the rule, as represented in Pl. II, fig. 4. We shall find that in this position, all the other numbers on the slider will be the moduli corresponding to the respective bases of each different system, on the rule. Thus, the 1 on the slider, or the modulus of the hyperbolic system, is opposite to 2.718, the basis of that system. On the other hand, the division 2 on the rule is opposite to 1.4427, which is the modulus of the system having for its basis the number 2. Carrying the eye still more to the left, and observing the point where similar divisions appear both on the rule and the slider, we shall find it to be at the number 1.76815, which therefore expresses the modulus and the basis in that particular system in which they are both equal. The reason of the above process will readily appear when it is considered, that the modulus of every system is the reciprocal of the hyperbolic logarithm of its basis.

This inverted condition of the slider will also afford an easy method of solving exponential equations, for which there exists no direct analytical method. The following may serve as an example. Let the root of the equation $x^x = 100$ be required. Set the unit of the inverted slider under 100 on the rule, and observe, as before, the point where similar divisions coincide; this will be at 3.6, which is a near approximation to the required root: and accordingly $3.6^{3.6} = 100$.

The principle of the instrument above described might be

applied in a variety of different forms to these several purposes: and I shall beg leave to notice one or two that offer some peculiarities. If to the upper scale, which we may suppose to be fixed, and to be graduated logometrically, constituting, as we have already seen, the line of exponents, a slider be adjusted, graduated on both edges, according to the logometric logarithms; and the line below, which like the upper one is supposed to be fixed, be graduated in the same manner as the slider, the instrument will possess the following property. When the division 10 on the slider is set against any particular number, or exponent, in the upper line, all the numbers on the lower line will be the powers, to the same degree, of the numbers opposite to them on the slider: the degree of the power being marked by the exponent on the upper line which is above the 10 on the slider. The lower line, therefore, will exhibit the whole series of similar powers belonging to all possible roots; and conversely, the slider will exhibit all the roots of the same dimension, with regard to all possible numbers. Thus, if the 10 on the slider be under 3 in the line of exponents, it will itself be above 1000 (which is its cube) in the lower line; all the other numbers in that line will be the cubes of their opposites on the slider; and, conversely, the former will every where be the cube roots of the latter. This will be sufficiently apparent, when it is recollected that the addition or subtraction of logometric logarithms answer to the multiplication or division of simple logarithms, and therefore to the involution and evolution of numbers. The rule in this form, therefore, bears a closer analogy to the common sliding-rule; since in every position it exhibits the series of similar powers and roots, exactly in

the same way as the latter exhibits the series of similar products and quotients.

I have also contrived another form of the instrument which possesses some advantages in theory, though its execution may perhaps be more difficult. It is evident that the whole scale may, like GUNTER's line, be thrown into a circular form; and this I have done in the way represented in Pl. III. The circle on the outside, being logometrically divided from 1 to 10 round the circumference, will constitute the line of exponents. The line of powers, being disposed in a spiral, will occupy the interior space, which may be made to revolve within the former, and should be provided with one or more threads extending from the centre to the circumference, and serving as radii to mark the position of all the parts of the spiral line with regard to the divisions of the outer circle. One of these threads may be fixed at the unit or beginning of the scale, and will serve to mark the position for the root of any required power. The spiral itself must be graduated exactly as the upper line in the first described rule: that is, the situation of the division 10 must be first determined upon, and then brought under the unit in the circle of exponents, that is, under the fixed thread. Every other division must then be marked with reference to the place of its logarithm on the circle, or must be made to occupy the same angular distance from the thread. This graduation will be most conveniently made by means of the moveable leg of a sector revolving on the centre of the circle. The comparison of the divisions of the spiral with those of the circle, may be made, either with this moveable sector, or with the threads already mentioned. The numbers on the spiral will increase

as they recede from the centre, and each turn will carry on the powers to an exponent 10 times higher than the preceding: and the converse will obtain with regard to the descending portion. Thus, immediately in a line with the 10, on the superior branch of the spiral, is found the number 10000000000, or 10^{10}: below it on the inferior branches, we find successively $1.258926 = 10^{0.1}$, $1.023293 = 10^{0.01}$, $1.00230524 = 10^{.001}$, $1.0002302\overset{8}{8}5 = 10^{.0001}$, $1.0000230261 = 10^{.00001}$, &c. of which, agreeably to the remarks that were formerly made, the decimal figures approach nearer and nearer to 2.302585093, &c. the reciprocal of the modulus of the logarithmic system.

A much greater extension might be given to the scale, by multiplying the number of turns of the spiral corresponding to the decuple increase of the exponents: but the superior accuracy thus obtained would probably be overbalanced by the diminished conveniency of application.

It is possible to exhibit in one view the whole series of roots, powers, and exponents, in all their possible relations, by the following disposition of lines. Let the lines AB, AC, (Pl. IV.), which I shall call respectively the line of exponents, and the line of roots, be drawn at right angles to each other, and a diagonal AD, or line of powers be drawn, bisecting this angle. Divide AB logometrically, so that the unit of the scale shall be at A: upon the same scale, divide AC into logometric logarithms, and AD into similar parts, by perpendiculars from the divisions of AC.

Through all these points of division, let there be drawn perpendiculars to the respective lines: and let each of these perpendiculars be considered as referring always to the numbers on the lines from which they are drawn. The following

relation will be preserved between the numbers belonging to any three of these perpendiculars that meet in one point; viz. that the number of the perpendicular to the line of roots, raised to the power expressed by the perpendicular to the line of exponents, shall be equal to the number denoted by the perpendicular to the line of powers. To find, for example, the second power of 3; following the perpendicular from the division 3 on the line of roots, and that from the division 2 on the line of exponents, till they meet in the point *e*, we find among the other set of perpendiculars, the line *fg* passing through the same point, which, followed till it meets the line of powers, indicates on it the number 9, which is accordingly the second power of 3. A similar process in other directions will furnish the root when the power and exponent are given, or the exponent when the root and power are given. We may thus perceive, at a single glance, not only all the powers of any particular root, and all the roots of any particular power; but also all the exponents of the series of powers belonging to the same root, as well as the similar powers of every possible root.

It is, perhaps, superfluous to observe, that the same method is applicable to the common scale of GUNTER; and that a table constructed accordingly, by dividing the sides as well as the diagonal logometrically, and applying three sets of perpendiculars, would, by their intersections, exhibit in one view all possible products and quotients resulting from all possible factors or divisors.

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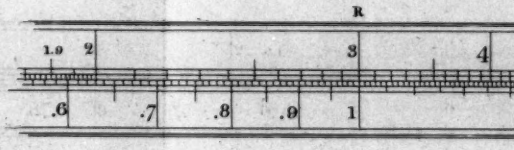
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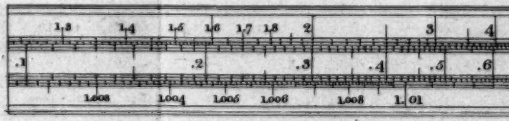
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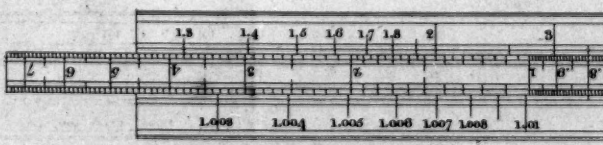
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Fig. 1.

Fig. 2.

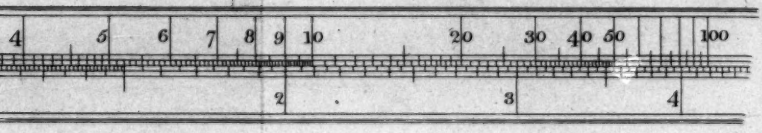

Fig. 3.
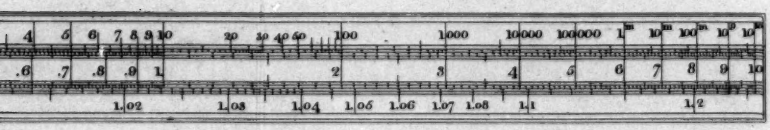
Fig. 4.

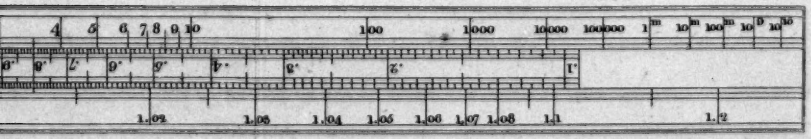

Fig. 5.

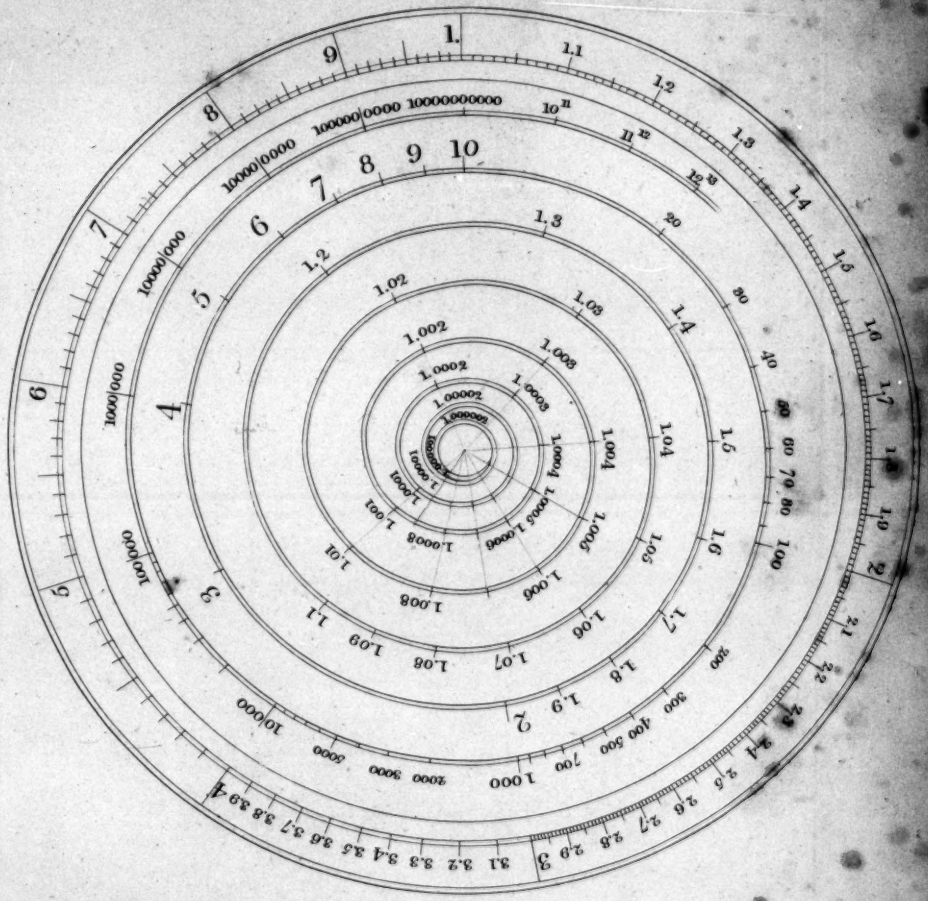
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Fig. 6.

P. Clouet sc.

III. *Experiments on the depolarisation of light as exhibited by various mineral, animal, and vegetable bodies, with a reference of the phenomena to the general principles of polarisation.* By David Brewster, *LL. D. F. R. S. Edin. and F. S. A. Edin. In a letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. K. B. P. R. S.*

Read December 15, 1814.

Dear Sir,

Towards the end of the year 1812, when I was engaged in examining the light transmitted through diaphanous bodies, I discovered the property which many of them possessed of *depolarising* the rays of light, or of depriving them of the polarity which they had received, either by reflection from the surface of a transparent body, or by transmission through a plate of agate. A short account of these experiments, which were exhibited to many of my friends in Edinburgh, was soon afterwards published in my treatise on new philosophical instruments.

As this singular property was possessed by numerous substances that exhibited no marks of double refraction, and even by animal and vegetable products, such as horn, tortoise-shell, and gum Arabic, it appeared necessary to distinguish it by a new name, and to refer it to a species of crystallization different from that of doubly refracting crystals. The circumstance, however, of agate and Iceland spar possessing

the faculty both of polarising and depolarising light, and the constant relation in the position of the axes which regulated these apparently opposite actions, induced me to think that the two classes of phenomena had the same origin. This opinion was afterwards strengthened by an experiment with a bundle of glass plates, in which light was depolarised by polarising it in a new plane; but in applying the principle to other phenomena, I was baffled in every attempt to generalise them. By extending, however, and varying the experiments; by examining the optical properties of every substance which I could command, and by comparing their structure with the phenomena which they exhibited, I have been led to the general principle to which they all belong, and to a series of results which, from their very nature, could not easily have been established by direct experiment. These conclusions, independently of their optical consequences, are peculiarly interesting to the chemist and the natural philosopher, by disclosing the structure of organised substances, and exhibiting new relations among the bodies of the animal, the vegetable, and the mineral kingdoms.

In proceeding to illustrate this subject, I shall first give some account of the experiments on which the theory is founded, and then explain the theory itself, and the conclusions which it seems to involve.

I. *Experiments on the depolarisation of light.*

I have already explained, in a former paper,* the general phenomena of depolarisation, and have shewn that almost all regularly crystallized bodies, such as plates of mica, of calca-

* Philosophical Transactions, 1814, Part I, p. 199.

reous spar, and of topaz, have two *neutral* axes at right angles to each other, and two *depolarising* axes at right angles to each other, and forming angles of 45° with the neutral axes.

In *mica*, the neutral axes coincide with the diagonals of its primitive rhomboidal base.

In *calcareous spar* the neutral axes are coincident with the diagonals of any of its rhomboidal faces, while the depolarising axes are parallel to the sides of these faces; but when polarised light is transmitted along the short diagonal of the rhomb itself, there is no position in which it is depolarised, or in which the two images continue visible during the whole revolution of the prism of calcareous spar next the eye. The evanescent image is no doubt restored by the interposition of the rhomb, but this only shifts the vanishing place of the images which will continue to disappear alternately in every quadrant.

In *topaz*, the neutral axes coincide with the diagonals of the base of its primitive right prism, and the depolarising axes are parallel to the sides of any of its square faces.

The minerals, in which I have not found the property of depolarising light, are *muriate of soda*, or rock salt, *fluor spar*, and a crystal of *spinelle ruby*. I have cut numerous plates in different directions from a cube of muriate of soda, and have tried many specimens of fluor spar, but in none of them could I discover the least trace of depolarising axes.

The only mineral which depolarises light in every position, and therefore possesses no neutral axes, is the *diamond*. Out of *fourteen* specimens of this gem which I examined, *seven* depolarised light in every position; *four* did not depolarise light at all; *one* depolarised about a fifth part of the light,

one about half of the light, and *one* nearly the whole of the light.

Semi-opal, like the diamond, depolarises light in every position; but there is an obvious approximation to neutral axes.

In employing another class of bodies, we are presented with a series of very singular results, which not only develope new affections of light, but lead to important conclusions respecting the crystallization of organised and unorganised bodies.

1. *Gum Arabic.* This vegetable substance, which is formed by concentric coats, has no neutral axes; but depolarises light in every position. In a very thin chip, however, the neutral axes are distinctly visible. With a strong solution of gum Arabic in water, I formed a thin film of it upon a plate of glass. In two or three days it became very hard, but though I have kept it six months, it has not acquired the property of depolarising light.

2. *Gum from the cherry tree.* A plate of this gum about one-twentieth of an inch thick, and so soft as to yield to the gentlest pressure of the nail, depolarises light, but the image does not wholly vanish in the neutral axes. Another plate of the gum, but exuded from a different part of the same tree, and much softer than the former, depolarises only a small portion of light.

3. *Caoutchouc.* This gum is composed of concentric or parallel layers of a vegetable juice, which are successively indurated by exposure to the sun. When a thin plate of it is made transparent by pressure between two plates of glass, it exhibits no neutral axes, but depolarises light in every position, in whatever direction the film is cut from the mass.

When the film was so extremely thin, that it could not be made transparent by pressure between two plates of glass, I stretched it over the mouth of a tube upon a piece of plane glass, and prevented it by means of a cord from recovering its shape. A layer of Canada balsam being then placed both below and above the caoutchouc, and another plate of glass laid upon the upper layer of balsam, the film became perfectly transparent. When exposed to polarised light, it exhibited *neutral axes*, like the most perfect crystals.

When caoutchouc is dissolved by heat, it loses completely its property of depolarisation, but it gradually recovers its former structure, and after a certain number of days, it is again capable of depolarising light. A piece of caoutchouc, which had been melted by heat, resumed its faculty of depolarisation at the end of twenty-five days; but upon pressing it gently with my finger, its structure was again destroyed, and at the end of nineteen days, it depolarised a small portion of nebulous light. Another piece of caoutchouc, dissolved by heat, had not recovered its crystalline state at the end of six days. After standing eighteen days, it depolarised a considerable quantity of light, and at the end of five or six weeks, it was capable of restoring the whole of the vanished image.

4. *White wax.* When a piece of wax is melted and cooled between two plates of glass, or when it is merely pressed between them by the heat of the hand, it depolarises light in every position. The restored image, however, has a nebulous appearance.

5. *Rosin and white wax mixed.* Rosin alone has not the property of depolarising light. When it is mixed with an equal part of white wax, and is pressed between two plates of glass

by the heat of the hand, the film is almost perfectly transparent by transmitted light, though of a milky white appearance by reflected light. It has not the property of depolarisation when the polarised pencil is incident *vertically*, but it possesses it in a very perfect manner at *an oblique incidence*, and exhibits the segments of coloured rings.

6. *Cells of the bee.* The waxen partitions of the honey-comb, when rendered transparent by layers of Canada balsam, depolarise light in every position.

7. *Manna.* This substance, when melted by heat between plates of glass, depolarises light in every position.

8. *Camphor.* A small piece of this substance when pressed between two plates of glass, without the application of heat, depolarises light in every position.

9. *Balsam of Tolu.* When a thin plate of this substance is formed between plates of glass with the assistance of a gentle heat, it depolarises light in every position; and a considerable degree of heat is necessary to deprive it of its crystalline structure. When it is allowed to cool very slowly, it does not acquire the property of depolarisation.

10. *Withered film at the root of the Calla Ethiopica.* This vegetable film depolarises light, and possesses distinct neutral axes which are parallel and perpendicular to the stalk of the plant, or to the parallel veins in the film.

11. *The fibres of flax, hemp, and cotton.* These vegetable fibres depolarise light, and have perfect neutral axes parallel and perpendicular to the axes of the fibres.

12. *The thin white semi-transparent leaf of the sea-weed* depolarises a small portion of light, and its neutral axes are parallel and perpendicular to the axis of the leaf.

13. *Adipocire from muscular fibre.* This substance melts as easily as white wax. It depolarises light in every position, and crystallizes differently from wax, manna, and spermaceti.

14. *Adipocire from the burying ground of the church des Innocens at Paris.* This substance melts at as low a temperature as the preceding, and when cooled between two plates of glass, it crystallizes in concentric rings which appear through the microscope like clusters of islands in a map, surrounded with engraved circles. It has no neutral axes, but depolarises light in every position.

15. *Adipocire from biliary calculi.* This body crystallizes exactly like benzoic acid, which it resembles in appearance, shooting out spicula at angles of about 90°. It requires a very considerable heat to melt it; crystallizes rapidly, and depolarises light in every position.

16. *The benzoic and oxalic acids*, when melted by heat, and then cooled, depolarise light in every position.

17. *Spermaceti.* This substance, when melted and cooled, depolarises light in every direction; and when pressed between two plates of glass without the aid of heat, it exhibits traces of coloured rings by polarised light.

18. *Gold beaters' skin.* Having procured a remarkably thin film of this animal substance, I rendered it transparent by placing it between layers of Canada balsam. It possessed the property of depolarising light, but it did not restore the whole of the evanescent pencil. Its neutral axes were not so perfectly developed as in the thin film of caoutchouc.

19. *Transparent and common soap.* A plate of transparent soap of any thickness depolarises light in every position; and

a thin film of the common yellow and white soap has the same property.

20. *Human hair.* The fine transparent hair of a child depolarises light, and possesses the most perfect neutral axes. These axes are parallel and perpendicular to the axis of the hair.

21. *Bristles of a sow* possess the same properties as hair. The neutral axes are seen more distinctly in this than in the preceding experiment, on account of the greater magnitude of the bristles.

22. *The fibres of silk and wool* depolarise light, and have neutral axes parallel and perpendicular to the axes of the fibres.

23. *The silkworm gut* and *sheep gut* depolarise light. In the former the neutral axes are perfectly developed, but in the latter there is merely an approximation to them.

24. *The human cuticle* depolarises light in every position.

25. *Parchment* depolarises light in every direction. In two positions, at right angles to each other, the restored image is indistinct and principally nebulous; while in other two positions at right angles to each other, at angles of 45° with the former, the restored image is distinct.

26. *The horny excrescence* on the human foot depolarises light in every position.

27. *The transparent film* at the joints of the claws of the common Partan depolarises light; and has neutral axes parallel and perpendicular to the length of the claw.

28. *The human nail* depolarises light in every position.

29. *A quill*, and the *thin film* which lines the inside of it, depolarise light. The former exhibits coloured rings, and the latter has distinct neutral axes.

30. *The cartilaginous breast bone of a chicken* depolarises light, and has neutral axes parallel and perpendicular to the longitudinal direction of the bone.

31. *The transparent cartilage* from the shoulder of a sheep has neutral axes, and produces the coloured rings by polarised light.

32. *The transparent edge* of the small fibres which compose the feathery part of a *quill* depolarise light, and have their neutral axes parallel and perpendicular to the axis of the fibre. It forms also an extraordinary prismatic image of the candle by transmitted light.

33. *The down of goose and ostrich feathers* depolarise light. Feathers from the neck and tail of a cock have neutral axes parallel and perpendicular to the direction of the fibres.

34. *Flat bones of a cod.* These bones depolarise light in every position, and exhibit coloured rings by polarised light. The soft cartilaginous substance, which is sometimes connected with them, possesses the same properties.

35. *Cylindrical bones of fish.* These bones depolarise light, and have their neutral axes parallel and perpendicular to the axis of the cylinder. They exhibit also colours by polarised light.

36. *Ivory.* A very thin film of ivory possesses neutral and depolarising axes, as perfectly as the most regularly crystallized mineral. When the vanished image is restored by the ivory, the intensity of the light of the other image is very much diminished, the difference between the two images being greater than I have found it in any other body. The film of ivory forms by transmitted light two highly coloured images

on each side of the common image, like those which I have described in my paper on mother of pearl.*

37. *Whalebone* depolarises light, and has neutral axes parallel and perpendicular to the direction of the fibres.

38. *Horn*. This substance also depolarises light in every position, and exhibits the coloured rings by polarised light.

39. *Mother of pearl* depolarises light in every position when the polarised pencil has a small angle of incidence; but when the angle of incidence is about 60°, and the plate about the thirtieth of an inch thick, it acts exactly like a bundle of glass plates, shifting merely the vanishing place of the image. †

40. *Bladder of a cow* depolarises light in every position.

41. *Human cornea* depolarises light in every position, and exhibits coloured rings by polarised light. The *tunica retina* and the *crystalline lens* exercise no peculiar action on light.

42. *Cornea of a cow* depolarises light in every position, and exhibits colours by polarised light. When it is pressed hard between the lenses, so as to induce a milky opacity, it still retains the power of depolarisation. The crystalline lens does not possess any of these properties.

43. *Cornea of a fish* depolarises light in every position, but most powerfully near its junction with the sclerotic coat, and exhibits coloured rings by polarised light. The crystalline lens, the sclerotic coat, and the capsule of the crystalline lens, exercise no action upon polarised light. When two capsules

* Phil. Trans. 1814. Part II. p. 397.

† We have here omitted the consideration of the nebulous image formed by mother of pearl at an oblique incidence. An account of the remarkable optical properties of this substance has been given in another paper.

were put together, a partial depolarisation took place, arising probably from the obliquity of the folds.

44. *Glue* depolarises light in every position.

45. *Hard isinglass* depolarises light in every position. When dissolved in water, it acquires this property a few hours after coagulation.

46. *Acetate of lead.* This salt melts at a temperature not much greater than that of bees' wax, and takes a long time to cool and crystallize. It depolarises light in every position. When the plates of glass, in which it is included, are considerably inclined to each other, the acetate of lead developes a second image in the act of cooling, but owing to the crystallization which takes place, both the images are imperfectly visible. Its refractive power increases a little after crystallization, and the new image that is developed is the one that is most refracted.

47. *Glass of borax.* A thick piece of this glass depolarises light in every position. Another piece of considerable thickness had no effect upon polarised light.

48. *Amber* sometimes depolarises light in every position, and sometimes exhibits neutral axes.

49. *Gum anime.* A piece of this gum, three quarters of an inch thick, depolarises light in every position, and seems to produce the complementary colours by polarised light. Small fragments of it depolarise only a small quantity of light.

50. *Sulphur*, when melted between two plates of glass, depolarises light in every position. It acquires this property in a few minutes.

51. *Ice.* Some plates of ice depolarise light in every position, while others exhibit neutral axes.

52. *Oil of mace.* This soft solid exhibits optical properties of a very peculiar character. When it is pressed into a thin film between two plates of glass without the aid of heat, it depolarises light in every position. It melts nearly at the temperature of blood heat, and takes a long time to cool and crystallize. If a thin plate of it is melted, and afterwards cooled between two pieces of glass, the image of a candle when seen through some parts of it, is encircled with a halo of nebulous light, varying in different plates from 0° to 16° in diameter, and having its central parts of a bluish colour, and the circumference of a reddish brown hue. In other parts of the film the halo disappears.

When the polarised light of a candle is transmitted through those parts of the film which do not produce the halo, it is depolarised in every position; but when the light is transmitted through the marginal parts, or those which produce the halo, the oil of mace restores *four wings of light* or *four luminous sectors*, in the centre of which is the place of the evanescent image. Through intermediate parts of the film, it depolarises two luminous images of the candle, separated by a narrow dark space, and manifestly formed of condensed nebulous light. Upon moving the film from the position which gives the luminous sectors, into that which gives the complete image of the candle, the wings or sectors gradually diverge from their common centre, and then vanish; and upon moving the film from the same position into that which gives the two luminous images, each adjacent pair of the sectors approach one another, and are condensed into two luminous semi-circles, which form the two images already mentioned. In the dark space between these two images, the

vanished image reappears by the slightest motion of the prism of calcareous spar. In some plates of oil of mace, this dark interval is occupied with a third image, so that the depolarised image has the appearance of being composed of *three images* closely pressing upon each other. In other plates the bright image is partly depolarised, even when the luminous sectors are visible.

The phenomena of the luminous sectors will be understood from Pl. V. fig. 1, where AB is the plane in which the light of the candle is polarised, and M N the two images of it formed by a prism of calcareous spar, *m* being the place of the vanished image, and *n* the visible image. The evanescent image at *m* is surrounded with the four luminous sectors 1, 3, 5, 7, separated by dark sectors 2, 4, 6, 8. The bright image of the candle at N is also surrounded with four luminous sectors 9, 11, 13, 15, separated by dark sectors 10, 12, 14, 16; but these sectors, of which 11 and 15 are the brightest, are not nearly so luminous as those at M.

If the oil of mace is kept in one position, while the prism of calcareous spar is turned round so as to make the image N move about M, as a centre in the direction BC, the evanescent image of the candle begins to appear at *m*: the luminous sectors turn round in the direction 1, 2, 3, 4, 5, 6, 7, 8: the sectors 1, 5 grow fainter, and 9, 13 brighter; and after the image N has moved through an arch of 45°, the two images M and N have nearly the same appearance. When the image N has described an arch of 90°, the sectors have the appearance represented in fig. 2, the candle having regained its full lustre in the middle of M, and having vanished in the middle of *n*. The sectors 1, 5 are now the faintest of those round

m, all of which are much inferior in brilliancy to those with which *n* is encircled.

When equal parts of *rosin* and *oil of mace* are mixed together, a film formed out of the mixture depolarises, imperfectly, the four luminous sectors.

53. *Tallow.* When tallow is melted between two plates of glass, and then slowly cooled, it exhibits no optical indications of a crystallized structure. After having stood five or six days, an incipient crystallization is exhibited in the property which it acquires of depolarising a small portion of nebulous light. This nebulosity gradually increases: about the eleventh day, it assumes an imperfect resemblance to the four luminous sectors produced by oil of mace; and about the sixteenth day, the form of the sectors is fully developed. Another plate formed of the fat of mutton, after standing five months, has acquired in some parts the property of depolarising a portion of nebulous light, while, in other parts, it depolarises a small part of the bright image. In a third plate, suddenly cooled by immersion in cold water, very faint traces of four large luminous sectors were visible by a careful exclusion of extraneous light.

54. *Tortoise shell* depolarises light in every position, and produces the coloured rings by polarised light. When a candle is viewed through tortoise shell, it is surrounded with a double halo, which becomes elliptical by inclining the plate to the incident rays. When the polarised light of a candle is depolarised, the restored image is surrounded with four very faint luminous sectors, like those in oil of mace.

55. *Heated glass.* When glass is brought nearly to a red heat, it depolarises light in every position, and the quantity

of depolarised light diminishes gradually with the temperature.

56. RUPERT'S *drops of unannealed glass.* When drops of melted glass are suddenly cooled by immersion in cold water, they acquire the faculty of depolarising light in every position, and of exhibiting the coloured rings by polarised light. At a certain thickness of the tail of the drop, the neutral axes are perfectly developed, and are parallel and perpendicular to the axis of the tail.*

57. *The semi-transparent and flat extremity of one of the legs of a young partan* gives only a nebulous image of a candle, but depolarises the nebulous light in every position.

58. A *tubular film* from the body of a partan, depolarises a small quantity of nebulous light.

The following table contains a list of substances chiefly of animal and vegetable origin, which have no effect in depolarising light.

Gold leaf.	Sclerotic coat of a fish.
Some crystals of diamond.	Crystalline lens of a fish.
Muriate of soda.	Crystalline lens of a cow.
Fluor spar.	Capsule of the crystalline lens of a fish.
A crystal of spinelle ruby.	Ambergris melted and cooled.
Muriate of ammonia.	Film which surrounds the hydatids.
Rochelle salts dissolved, and crystallized on the side of a glass.	Delicate film which lines the ribs of a lamb.
	Film from the stalk of the rhubarb.
Nitrate of lead dissolved, and crystallized on the side of a glass.	Film, or epidermis, which covers the shell *solen ensis*.

* A full account of the properties of heated and unannealed glass will be found in two former papers. (Phil. Trans. MDCCCXIV. Part II. p. 436, and MDCCCXV. Part I. p. 1.)

Resin of bile melted and cooled.
Jelly from calves' feet.
The skin of a fowl.
Scale from the body of a bee.
Hair of a bee.
Wing of a bee.
Wing of a house beetle.
Wing of the May fly.
Wing of the stone fly.
The byssus, or hair from the *fiona marina*.
Wing of the *meloë vesicatorius*.
Film which covers the tubular stalk of the *leontodon taraxacum*.
Film between the coats of an onion.
Film on the leaf of the American house leek.
Leaf of the hydrangea.
Spatha of a lily.
Film of gum Arabic formed by evaporation.
Rosin.
Gum copal.
Thin fragments of gum anime.
Gum galbanum.
Gum juniper.
Crystals balsam indurated.
The spheres on sea-weed.
Film which lines the stalk of the *fleur de lys*.
Thin slices from a wafer.
Filaments of the pappus of the *leontodon taraxacum*.
Film which lines the shell of an egg.
Skin of a dried grape.
Phosphorus.
Hair from the fur of a seal.
Skin of an infant eleven months old.
Skin of a child two months before birth.
Skin of a herring.
Gum mastic.
Burgundy pitch.

II. *Theory of the depolarisation of light.*

The various modes in which bodies depolarise light may be reduced to *seven*.

1. When the crystal possesses neutral axes, and forms two images which are capable of being rendered visible, as in *calcareous spar*, *topaz*, &c.

2. When the crystal possesses neutral axes and exhibits only a single image, as the *human hair* and various *transparent films*.

3. When the crystal has no neutral axes, but depolarises light in every position, as in *gum Arabic*, *caoutchouc*, *tortoise shell*, &c.

4. When there is an approach to a neutral axis, as in *gold-beater's skin*, &c.

5. When the crystal depolarises, or restores only a part of the polarised image, as in a *film of sea-weed* and a *film* from the *parian*.

6. When the crystal depolarises luminous sectors of nebulous light, as the *oil of mace*.

7. When the crystal restores the vanished image, but allows it to vanish again during the revolution of the calcareous spar.

1. The *first* of these modes of depolarising light admits of an easy and satisfactory explanation.

Let R*r*, fig. 3, be the light of a candle completely polarised by reflection in the direction *r*S from the surface of the transparent body AB. If this light is viewed through a prism of calcareous spar CD,* when its principal section is neither coincident with, nor perpendicular to the plane of reflection R*r*S, two images of the candle will be seen; but upon turning round the prism CD, one of the two images will vanish alternately in every quadrant of the circular motion of the prism. Let the prism therefore be fixed in the position which it has when one of the images has vanished, in which case the principal section will be either parallel or perpendicular to the plane R*r*S. If a rhomb of calcareous spar MNOP is now interposed, so that the principal section MN is either parallel or perpendicular to the plane R*r*S, the vanished image will still be invisible. Upon turning round the rhomb MNOP, the

* Another prism is represented in the figure for the purpose of correcting, as much as possible, the refraction and dispersion of the prism of calcareous spar.

vanished image will begin to appear, and when MO is in the plane of reflection R*r*S, it will have reached its maximum brightness. It will again vanish when OP is in the plane of reflection, and will again recover its lustre when ON is in that plane, having vanished and reappeared *four* times in the course of one revolution of the rhomb. If the rhomb MNOP is kept fixed when the vanished image has reappeared; and if the prism CD is turned round, the two images will continue visible during every part of its circular motion, and hence the polarised ray *r*S, seems to have been robbed of its polarisation or depolarised.

In order to explain these appearances, let CD be fixed in its former position, and let the rhomb MNOP have its principal section or neutral axis in the plane R*r*S. This rhomb is known to give two images of the candle formed by rays ST, SV, nearly coincident, but owing to its present position, one of the pencils, that would have moved in the direction ST, refuses to penetrate the rhomb, and therefore only one pencil SV, polarised in the same manner as *r*S, falls upon the prism CD. Now this prism being obviously placed in the position where its power of doubling SV is extinguished, that is, where one of the pencils, into which it separates SV, has vanished, a single image E of the candle will still only be visible, notwithstanding the interposition of the rhomb. The very same reasoning is applicable to the case where the longer diagonal OP is in the plane of reflection.

The prism CD continuing fixed, as before, let the side MO, or the depolarising axis of the rhomb, be brought into the plane of reflection. In this situation of the crystals, both the pencils ST, SV, fall upon the prism CD, which has now the

particular position that enables it to double each of these pencils; so that *four* images of the candle 1, 2, 3, 4, will now be visible. As the rhomb MNOP produces only a very small separation of the pencils ST, SV, the two images 1, 2, will overlap each other, and resemble only one image at E, while the other two images 3, 4, will appear as a single image at F. Every thing remaining fixed, let the prism CD be turned round in a plane perpendicular to ST. The effect of this will be to extinguish one of each of the double images E and F at every quarter of a revolution, that is, first the images 1 and 3, then the images 2 and 4, then the images 1 and 3 again, and last of all the images 2 and 4. Still, however, one image is always left at E and another at F, so that when the polarised ray *r*S passes through the depolarising axis MO of the rhomb, the two images E and F continue visible in every part of the motion of the prism. The depolarisation, therefore, of the pencil *r*S, is nothing more than the polarisation of it in a new plane, and the depolarising rhomb MNOP acts in every respect like a doubly refracting and polarising crystal.

2. In the *second* kind of depolarisation where the *human hair*, or a *plate of mica* is substituted in place of the rhomb of calcareous spar, the phenomena are precisely the same as those which have been described in the preceding section, and therefore we are necessarily led to suppose that the human hair and the mica form two images polarised in an opposite manner, like those given by calcareous spar. These two images indeed being produced by the same, or nearly by the same refractive power, cannot be rendered visible by any contrivance; but when we consider that the depolarising axes of the mica coincide with the long and short diagonals of its

primitive rhomboidal base, as in the case of calcareous spar and topaz, and that there is a variation in the intensity of the light of the images E and F, during the revolution of the prism, we must consider the existence of two oppositely polarised images as no longer problematical.

Hence it follows, that every substance which possesses the property of depolarising light in the second manner, must necessarily form two coincident or nearly coincident images polarised in an opposite manner; or to speak more correctly, a pencil of common light transmitted through depolarising crystals, consists of a portion of light polarised like one of the pencils formed by calcareous spar, and of another equal portion polarised like the other pencil formed by calcareous spar.

Depolarising substances, consequently, are not entitled to the name of *doubly refracting crystals*, when the two oppositely polarised pencils are not capable of being separated from each other, and till this separation is actually *seen*, we must consider the two pencils as produced by the same refractive power.

We would therefore propose to designate all substances that form two separable images, such as calcareous spar, quartz, topaz, &c. by the name of *doubly refracting crystals*, and those which do not form two separable images, such as diamond, mica, heated glass, the human hair, &c. by the name of *doubly polarising crystals*.

3. The *third species* of depolarisation is characterised by the substance having no neutral axes, and depolarising light in every position; and is possessed by *gum Arabic*, *caoutchouc*, and many other bodies which are known to be formed by the successive deposition and induration of thin layers.

When the first layer of gum Arabic or caoutchouc is deposited and crystallized, it will possess both neutral and depolarising axes like every other crystal. The second layer will likewise have these axes, but there is manifestly no cause which can make the neutral and depolarising axes of the second layer coincide with those of the first layer; so that after a number of layers are formed, there will be a depolarising axis in every direction. In order to illustrate this conclusion by direct experiment, we have only to place one plate of mica above another, so as to make the neutral axis of the one coincide with the depolarising axis of the other. It will then be seen that all the axes become depolarising axes, and that the compound crystal acts upon light exactly like gum Arabic and caoutchouc. If this explanation be correct, we should expect to find, that a film of gum Arabic or caoutchouc, reduced to a less thickness than any individual layer, would exhibit its neutral axes, and lose the property of depolarising light in every position. This interesting result I have repeatedly obtained both with gum Arabic and caoutchouc, as described in experiments 1 and 9, so that we have both a synthetical and an analytical proof of the explanation which has been given of the *third* kind of depolarisation.

Hence it follows, that all substances which depolarise light in every position, are formed by layers successively deposited and crystallized; that every layer has neutral and depolarising axes, like regularly crystallized bodies; and that the axes of one layer is not related in point of direction to those of its adjacent layers.

4. The *fourth* kind of depolarisation is exhibited in the film of gold beaters' skin, where there is an approach to a neutral axis.

When a body is composed of two or more films whose neutral axes are nearly coincident, the compound film will exhibit the fourth kind of depolarisation, and the approximation to a neutral axis will be more or less perfect, as the coincidence of the axes is more or less complete. This phenomenon is most likely to be exhibited by thin plates which are composed of a small number of films.

Hence every body, in which there is an approach to a neutral axis, must be composed of two or more films, whose neutral axes happen to be nearly coincident. These films are probably deposited and crystallized at different times; or if their crystallization has been simultaneous, the forces, or causes by which it was produced, must have acted independently of each other.

5. The *fifth* kind of depolarisation takes place when there is an approach to a depolarising axis, or when the crystal restores only a portion of the vanished image.

If we suppose one part of a body to have no crystalline texture, while another part of it has the structure necessary to depolarise light, it will exhibit correctly the *fifth* kind of depolarisation. The uncrystallized portion being incapable of restoring any part of the vanished image, the light which it transmits will form no part of the depolarised pencil, which will consist merely of the rays transmitted through the structure which has the property of *double polarisation*. The magnitude, therefore, of the depolarised pencil will be a measure of the portion of the substance which has undergone crystallization. From the phenomena of caoutchouc, this explanation derives great support. When the crystalline texture of this substance has been destroyed by heat, it ceases to act upon

polarised light. After it begins to crytallize, however, a *small portion* of light is at first depolarised. This portion gradually increases, and the image is not completely restored till the crystallization has pervaded the whole mass. The experiments with oil of mace furnish us with another proof of this explanation, and exhibit a case in which a part of the substance is permanently crystallized, while another part of it is permanently uncrystallized.

Hence we may conclude, *that bodies which depolarise only a portion of light, either consist of permanently crystallized and uncrystallized portions, or are in a state of approach to a perfect crystalline structure, the crystallized portion being always proportional to the quantity of depolarised light.*

6. The *sixth* kind of depolarisation is exhibited in the curious phenomena of *oil of mace*, which sometimes depolarises *four* sectors of nebulous light.

Those plates of oil of mace, in which the luminous sectors are alone depolarised, have obviously two structures, namely, that which forms the bright, and that which forms the nebulous image. The structure which forms the bright image has no more action upon light than a mass of water, as it does not in the slightest degree alter its polarity; but the structure which forms the luminous halo possesses a peculiar character. If we suppose the halo to be divided, as in Pl. V, fig. 1; into eight sectors 1, 2, 3, 4, 5, 6, 7, 8, every alternate sector 1, 3, 5, 7, is polarised in the same manner as the incident light, while the other sectors 2, 4, 6, 8, are polarised in an opposite manner. Now, if this halo consisted only of one nebulous image, the evanescence of every alternate sector would take place without applying the calcareous spar, and merely by

transmitting polarised light through the oil of mace; but as this is not the case,* it necessarily follows that there are *two* halos, or nebulous images, the one lying exactly above the other, and having every alternate sector polarised in an opposite manner, while each sector in the one image has an opposite polarisation to the corresponding sector in the other image. An idea of this curious property may be formed from fig. 4, in which we have shown the two halos at a distance, and distinguished the opposite kinds of polarisation by the signs + and −.

Those parts of oil of mace which depolarise a portion of the bright image, while they form the luminous sectors, have therefore the faculty of forming *four images*, two bright and two nebulous, possessing the characters which have already been described.

The two adjacent images which are formed by some portions of the plate of oil of mace, are obviously produced by the sectors 1, 7, and 2, 5, fig. 1 being condensed on each side of *m*, and when three images are depolarised, the third image is a portion of the bright image restored at *m*, the place of its evanescence.

If we knew in what way the halo itself is formed, there would probably be no difficulty in explaining these remarkable phenomena. The diameter of the halo is too small to allow us to suppose that the polarisation of the sectors can be effected by oblique reflection or refraction, and though it is extremely probable that light is partially polarised by inflexion

* In some instances, when we examine the halo formed by polarised light without applying the calcareous spar, the two sectors in the plane of polarisation are less luminous than the rest.

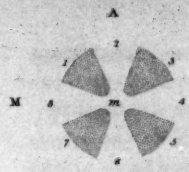


Fig. 1.

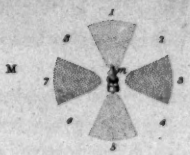
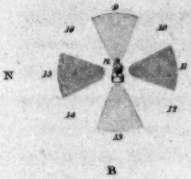
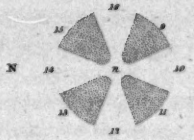


Fig. 2.

Luminous Sectors exhibited by Oil of Mace.





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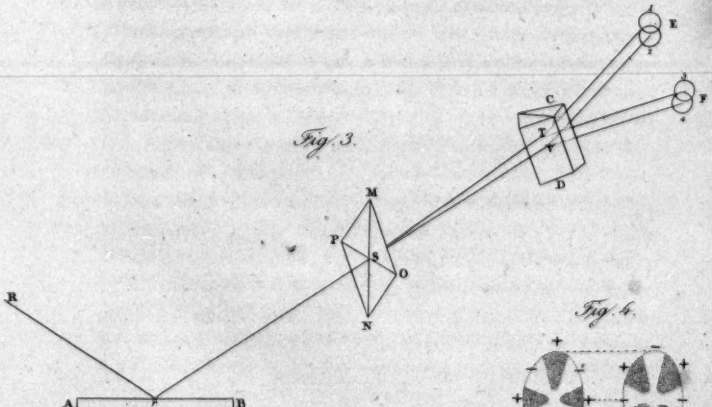
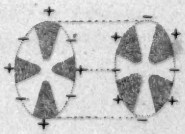


Fig. 3.

Fig. 4.



and deflexion, yet we are not entitled to employ this conjecture in the explanation of phenomena.

7. In all the preceding cases of depolarisation, the depolarised image continues visible in every part of the circular motion of the prism of calcareous spar, but there are cases where the vanished image is restored, and again vanishes during the revolution of the prism.

This phenomenon takes place when the polarised pencil is depolarised by transmitting it along the short diagonal of a rhomb of calcareous spar, or along the axis of a hexaedral prism of nitre, or through a parcel of glass plates, or through plates of agate and carbonate of barytes, that give a bright and a nebulous image. In all these cases only one bright image is produced, so that the images must vanish alternately in every quarter of a revolution, the only effect of the depolarising body being to polarise the light in a different plane, and thus to shift the vanishing place of the images.

Hence it follows that every body which possesses this kind of depolarisation, forms either a bright and a nebulous image, like the agate, or a single image, the light of which is all polarised in the same manner.

I have the honour to be, &c.

DAVID BREWSTER.

Edinburgh, October 22, 1814.

IV. *On an ebbing and flowing stream discovered by boring in the harbour of Bridlington.* By John Storer, *M. D. Communicated by the Right Hon. Sir* Joseph Banks, *Bart. K. B. P. R. S.*

Read January 19, 1815.

The following account of certain peculiarities attending a spring of fresh water, which was tapped in boring within the harbour of Bridlington quay, Yorkshire, is given from repeated observations made during a residence of some weeks there, in the months of July and August, 1814. The harbour of Bridlington quay is dry at low water, except for a rivulet which traverses its bed: at high water, it has from fifteen to seventeen feet of water.

Mr. Rennie, civil engineer, was consulted in the year 1811, respecting certain improvements projected in that harbour. At his desire, with a view to ascertain the depth of the stratum of clay in the harbour, the boring, which terminated in forming the well to be described, was begun under the direction of Mr. Milne, collector of the customs for the port. The spot fixed upon is opposite to the termination of a street leading to the harbour, and has about six feet of water, at high water, in ordinary tides.

After the workmen had bored through twenty-eight feet of very solid clay, and afterwards through fifteen feet of a cretaceous flinty gravel, of a very concrete texture, the auger was perceived to strike against the solid rock; but as they were not

able to make any impression upon it, the work was given up for that tide, without any appearance of water from the first. In an hour or two afterwards, the bore was found filled to the top with fresh water, of the most limpid appearance: it soon flowed over, and was even projected some inches above the summit of the bore, in a stream equal to its calibre. When it was ascertained that the water was of the purest quality and taste, perfectly fit for washing, and every culinary purpose, the bore was properly secured by an elm stock, ten feet long, and perforated with a three inch auger, driven to its full length: a copper tube, well tinned on both sides, of a circumference to admit its being passed through the bore of elm stock, and thirty-two feet in length, was then forced to the bottom of the bore, so as to rest on the rock. The upper part being properly puddled round the elm stock, and the well thus completed, the following singular circumstances were observed, and have continued with great uniformity ever since.

As soon as the surface of the sea water in the harbour, during the flowing tide, has arrived at a level of forty-nine or fifty inches lower than the top of the bore, the water begins to flow from it, in a stream equal to its calibre, the impetus of which is increased as the tide advances, and may be observed to be propelled with much force after the bore is overflowed by the tide. The discharge continues from four to five hours, *i. e.* till the tide in returning falls to the same level where it began to flow: at this point, it ceases completely till the next flood shall have regained the same level, when the same phenomena recur, in the same succession; and without any variation, but what arises from the different degrees of elevation in the tides. The rule appears to be, that the

column of spring water in the bore, is always supported at a height of forty-nine or fifty inches above the level of the tide, at any given time. This at least was the result of every observation I made during several successive weeks, in the months of July and August last; and I am assured by Mr. MILNE, on whose ingenuity and habit of accurate observation I can place the firmest reliance, that his habitual experience, for three years past, goes to convince him, that the variations from the rule stated above, are very inconsiderable during the summer and autumnal months; but that in winter, after any unusual fall of rain, he has known the column of fresh water raised eight feet above the level of the tide, and the period of its discharge proportionally prolonged.

For the use of the town and shipping, a reservoir of brick-work, capable of containing one thousand gallons, has been constructed within two or three yards, and upon somewhat a higher level than the summit of the bore, and is made to communicate with it by a tube of the same diameter, fitted with a valve, to prevent any reflux into the well. Two waste pipes are placed within a foot of the top of the reservoir, for the regular discharge of the water, and it has also been made to communicate with a pump adjoining, by which the reservoir may be emptied; and as the bore of the well is now closed and secured at the top, it is obvious that the commencement of the flow of water, from the pipes of the reservoir, will happen a few minutes sooner or later at each tide, according to the quantity of water it contained at the time. Such, however, is the known regularity of the discharge from the waste pipes, that at the expected time of the tide several of the inhabitants are always on the spot with

their vessels, and are rarely obliged to wait for more than five minutes.

Such is the state of facts, and it appears to open a subject of curious investigation to those whose habits and practical knowledge qualify them for it. The appearances seem not to admit of any satisfactory explanation, without supposing some mode of subterranean communication, by which the water of the sea, and that of the spring in question, are brought into actual contact, so as to exert a reciprocal action. This supposition receives considerable support from a circumstance which I had no opportunity to observe, but which Mr. MILNE has had frequent occasion to notice; and which he describes by remarking, that after stormy weather, when there is a heavy sea on that coast, the water is discharged, even from the waste pipes of the reservoir, with an evident undulation; which, of course, would be more considerable from the original bore.

Mr. MILNE has framed an hypothesis to satisfy his own mind on this curious subject. He believes the stratum of clay found in the harbour, to extend over the whole bay in front of it, as far as the Smithwick sand, which forms a bar across the opening of the bay, in a direction from Flamborough head towards the Spurn point, and about four miles from the quay in a south-easterly direction. This bank is supported by a reef of rock; and though there are openings, which are well known, and admit vessels of considerable burden at all times of the tide, there is in general but a small draft of water on this bank, when the tide is out. On the outward or east side, towards the ocean, the rock is quite perpendicular, and a great depth of water is immediately behind it. As the copious source

of water, which has been tapped in the harbour, lies at such a depth, and under a stratum of clay, there is no reason to think that it can be discharged any where in the bay, till it arrives at the ledge of rock where the clay terminates. Here, among the fissures of the rock, it may find its exit; and this is the more likely, as it is known that the bed of the sea at the back of the Smithwick sand, is at so much a lower level.

Admitting this supposition to be correct, or nearly so, it seems to follow, that the issue of a body of fresh water, through a fissure in rock forming the bed of the sea, would meet with more or less resistance at different times of the tide; because the two columns of fluid in meeting, would act upon one another in the ratio of the altitude of each, taking into the account the difference of their specific gravity; and thus, if there is any approach to an equilibrium, an operation would result, analogous to the flux and reflux of the tide, near the mouth of rivers.

This hypothesis is specious, and accounts for the flux and reflux of the water from the bore, as well as for the singular undulation of the discharge in a boisterous state of the sea: but the greater relative altitude to which the column of spring water is elevated after much rain, and the consequent prolonged discharge of it during each tide, seems to militate against its correctness; since, in a case, where by the supposition a balance is nearly established, an additional impetus communicated to the column of spring water, ought to produce the opposite effect, by enabling it to overcome the resistance of the same column of sea water during a longer period of each tide, than under the usual circumstances.

It is not improbable, that this whole subject might be

elucidated, by a more perfect acquaintance with the peculiarities of the springs on this part of the coast, provincially termed *gipsies*. The water in this district of the east riding of Yorkshire, possesses that limpidness which is usual in cretaceous soils; but for many miles of the Wolds behind Bridlington, very little water is to be seen. There are few rivulets, and these are very low in the summer, and most of them quite dry in autumn. The account to be collected from the inhabitants is, that in two or three weeks after the commencement of frost, the springs begin to run copiously; and in many, the water is projected with such impetuosity, as to resemble a *jet d'eau*; it is then that, in the language of the country, it is said, "the gipsies are up," and the rivulets overflow.

JOHN STORER.

Nottingham, Nov. 5, 1814.

Drawn up from Notes taken at the time, and on the spot.

V. *On the effects of simple pressure in producing that species of crystallization which forms two oppositely polarised images, and exhibits the complementary colours by polarised light.* By David Brewster, *LL.D. F.R.S. Edin. and F.S.A. Edin. In a letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. K.B. P.R.S.*

Read January 19, 1815.

Dear Sir,

In prosecuting the experiments on the depolarisation of light, which you lately did me the honour to lay before the Royal Society, I have been led to the discovery of a remarkable property of soft transparent solids, in virtue of which they exhibit, by simple pressure, all the optical qualities of doubly polarising crystals. In the paper on depolarisation to which I have now alluded, it has been shown that a mixture of bees' wax and rosin, when melted and cooled between two plates of glass, depolarises a ray which falls upon it at a vertical incidence, while the same substance, pressed between two plates of glass, without the aid of heat, produces no effect when the polarised ray falls perpendicularly upon it, but depolarises it at an oblique incidence. In this experiment the crystallization was not produced by pressure, as the unmelted bees' wax was already crystallized; but it is obvious, either that the pressure had modified the natural crystallization of the bees' wax, so as to enable it to depolarise only at an oblique incidence, or that its liquefaction between two plates of glass had

produced such a change, as to communicate to it the property of perpendicular depolarisation.

In whatever manner this difference of action was produced, the effects of pressure seemed to require farther investigation, and in order to be able to apply a sufficient force, without injuring the structure of the substance, I employed animal jellies which could be brought to any degree of tenacity without losing their transparency.

Having cut out of newly made calves' feet jelly, a cylindrical portion, about half an inch broad and half an inch high, I placed it between two plates of glass, and observed that it did not possess, in the slightest degree, the property of depolarising light. After standing some days, it began to depolarise light at its circumference, and in the course of fifteen days this property gradually extended to its central parts. The cylinder of jelly had at first such a slight degree of tenacity, that it quivered with the gentlest motion; it was now however considerably indurated, and though it formed a plate exactly parallel, yet it diverged the incident rays like a concave lens, from the external parts having a greater degree of induration, and consequently a higher refractive power than the parts towards the centre. At the end of three weeks it began to lose its transparency, and at the same time its depolarising structure; and in the course of a few days more, it had no more action upon light than a mass of water. Its thickness was now reduced, by contraction, to about one-seventh of an inch, and it possessed a degree of tenacity, approaching to that of caoutchouc, which enabled it to sustain, without injury, a very considerable degree of pressure.

In this state, I exposed the plate of jelly to the light of a

candle polarised by reflection, and employing a prism of Iceland spar, one of the images of the candle vanished at every quadrant of its circular motion, just as if the jelly had not been interposed. I now pressed together the two plates of glass, that inclosed the cake of jelly, and was surprised to find that the vanished image was restored, the light being depolarised in every position of the cake. Upon removing the pressure, the image again vanished, and the cake resumed its uncrystallized state.

In order to vary the experiment, I took two prisms of Iceland spar, and having put them in such a position that two of the four images of a candle vanished; I then placed the cake of jelly between the prisms, and pressing them hard together, the two vanished images were restored, the depolarisation being more perfect as the pressure was increased. The removal of the pressure again destroyed the depolarising structure.

I repeated the preceding experiments with another plate of jelly, which was perfectly transparent, and which possessed the depolarising structure only at the edges. The pressure never failed to communicate to the central parts the property of depolarisation, and I repeatedly observed that the complementary colours produced by topaz, &c.* were imperfectly exhibited when the pressure had attained a particular magnitude.

As the cakes of jelly used in the preceding experiments, had both been crystallized by induration, I took another cylindrical portion that had never possessed that crystalline structure which is necessary to depolarise light. It was about an inch high, and three quarters of an inch broad, and was so

* See Phil. Trans. 1814. Part. I.

extremely soft that it could scarcely support itself in a vertical position. Having exposed it to a polarised ray, as before, I pressed its cylindrical circumference between my finger and thumb, and thus enabled it to restore the vanished image. A slight pressure, indeed, from one finger, was capable of producing a perceptible degree of depolarisation.

Instead of calves' feet jelly, I next employed *isinglass*, brought nearly to the consistency of caoutchouc. After standing a day, the isinglass had, of its own accord, acquired the depolarising structure, even when cut into very thin films, either parallel or perpendicular to the surface; but upon placing a cake of it, about a quarter of an inch thick, between two plates of glass, and exposing it to polarised light, I found that the complementary colours were developed in a most beautiful manner by hard pressure, and I often saw a portion of a red and a blue ring upon one of the images of the candle, while the colours complementary to these occupied the other image. By varying the pressure new colours arose, and when the pressure was removed, the complementary tints gradually disappeared. As these changes of colour might be ascribed to the pressure, only in so far as it reduced the cake of isinglass to the degree of thickness necessary for their production, I brought the cake to the same thickness which it possessed when exposed to the pressure that developed the most lively colours. No colours, however, were now visible, but they were instantly reproduced, as before, by the application of pressure.

I now melted the isinglass between two plates of glass, and allowed it to stand till it coagulated, which took place in less than a quarter of an hour. Upon transmitting through it a

polarised ray, I saw that it did not in the least degree depolarise it. I then exposed the included jelly to a considerable pressure, and it instantly restored the evanescent image, and exhibited, in a faint degree, the complementary colours. This plate was not more than $\frac{1}{20}$th of an inch thick.

From these experiments and others, which have been repeated under various modifications, it follows:

1st. *That soft animal substances which have no particular action upon light acquire, from simple pressure, that peculiar structure which enables them to form two images polarised in an opposite manner, like those produced by all doubly refracting crystals, and to exhibit the complementary colours produced by regularly crystallized minerals.*

2d *That soft animal substances, which already possess the property of depolarising light, receive from simple pressure such a modification in their structure as to enable them to exhibit, in a very brilliant manner, the complementary colours produced by crystallized minerals.*

3d. *That soft animal substances which only depolarise a portion of the incident ray, have their depolarising structure completed by simple pressure.*

The extension of these experiments to other soft substances, to hard bodies when in a fluid state, and to fluids themselves, may probably lead to still more interesting results.

I have the honour to be, Dear Sir,
your most obedient humble servant,
DAVID BREWSTER.

Edinburgh, January 3, 1815.

To the Right Hon. Sir JOSEPH BANKS, Bart. K. B. P. R. S.

VI. *Experiments made with a view to ascertain the principle on which the action of the heart depends, and the relation which subsists between that organ and the nervous system.* By A. P. Wilson Philip, *Physician in Worcester. Communicated by* Andrew Knight, *Esq. F. R. S.*

Read February 9, 1815.

THE following experiments were begun with a view to ascertain the manner in which certain poisons act in destroying life. I soon found that, in order to make any considerable progress in such an inquiry, it is necessary to ascertain how far the powers of the nervous and sanguiferous systems directly depend on each other. There seems never to have been any difference of opinion respecting the direct dependence of the nervous on the sanguiferous system. When the powers of circulation are increased or diminished, the nervous system always suffers a corresponding change, nor can the latter, under any circumstances, continue to perform its functions after the former are destroyed. I speak of the warm blooded animals. In cold blooded animals the process of dying is so slow, that the functions of the nervous system abate very gradually, after the circulation has wholly ceased. The converse of the above proposition is by no means so generally admitted. It is evident that certain changes of the nervous, produce corresponding changes in the sanguiferous, system; yet, while some assert, that the action of the heart

depends as immediately on the brain, as that of the latter does on the heart, others maintain, that the nervous power may be wholly destroyed without impairing the vigour of this organ. This point it is necessary to determine, before we can trace with precision the *modus operandi* of poisons. The following inquiry therefore may be divided into two parts. In the first, I shall endeavour to ascertain how far the power of the heart is influenced by the state of the nervous system; in the other, by what steps certain poisons destroy the powers of both. This I shall reserve for another paper, and here confine myself to the first part of the subject.

Till the time of HALLER, it seems to have been the general opinion, that the muscles derive their power from the nervous system. He taught, that the power of the muscles depends on their mechanism, that the nervous influence is merely a stimulus which calls it into action, and consequently that those muscles, the heart for example, which act only by the application of one peculiar stimulus, unconnected with the nervous system, are wholly independent of it. This opinion seemed confirmed by its being generally admitted, that the action of the heart continues after it is removed from the body, and that it cannot be influenced by stimulating the brain, or spinal marrow, or the nerves which terminate in it. HALLER and his followers maintain, that there are two distinct vital powers, one of the nervous and another of the sanguiferous system.

The supporters of HALLER's doctrine however, found many difficulties to contend with. The evident objections to it are, that the heart is influenced by affections of the mind, and that it is supplied with nerves. Various hypotheses have been

framed to get rid of these objections, some of which imply a considerable modification of the original opinion. Several writers have maintained, that although the heart is independent of the brain and spinal marrow, it may be subject to some peculiar action of its own nerves; others, that the ganglia through which its nerves pass have a power independent of the sensorium commune. FONTANA and others have maintained, that the nerves of the heart are absolutely useless; others, that these nerves are distributed on its vessels, and do not enter the substance of the heart. SCARPA, however, has proved, that nerves are distributed to the heart in the same way as to other similar parts. Nothing can show more strikingly the imperfection of our knowledge of this important branch of physiology, than that opinions so different, and so destitute of proof, should be maintained by the best writers upon it.

An author has lately appeared, who, among other ingenious and important experiments, has made many relating to this subject, and arrived at conclusions which have surprised physiologists, yet apparently so well supported as to have obtained their general assent. M. LE GALLOIS* maintains, that by the destruction of the whole or cervical part of the spinal marrow, the action of the heart is immediately so debilitated, that it is no longer capable of supporting the circulation; while by the destruction of the brain, on the contrary, its action is unimpaired: from which he infers, that it is from the

* Expériences sur le principe de la Vie, notamment sur celui des mouvemens du cœur, et sur le siège de ce principe, suivies du Rapport fait à la premiere Classe de l'Institut, sur celles rélatives aux mouvemens du cœur, par M. LE GALLOIS, Doct. en Méd. &c. Paris, 1812.

spinal marrow that the heart derives the principle of its life and of its motions. Those motions of the heart, says M. LE GALLOIS, which remain after the destruction of the spinal marrow, or the interruption of the nervous influence upon the heart in any other way, and which misled HALLER and his followers, are motions without force, incapable of supporting the circulation, and analogous to the motions of other irritable parts on the application of a stimulus, which in this case is the arterial blood contained in it.

The experiments, on which these opinions are founded, he repeated in the presence of a Committee of the National Institute at Paris, which has expressed its conviction of their accuracy. Notwithstanding this high authority, I was led, from some experiments which I made many years ago, in which both the brain and spinal marrow were destroyed by the action of opium and tobacco, to doubt M. LE GALLOIS' conclusions. The reader will judge how far the following experiments tend to invalidate these conclusions, and influence our opinions of the subject to which they relate.

I cannot here omit to express my thanks to Mr. HASTINGS, House-surgeon to the Worcester Infirmary, who assisted me in the following experiments. His expertness in dissection was often of great use, where it was necessary to be expeditious, and to lose as little blood as possible.

Exp. 1. A rabbit was deprived of sensation and voluntary power by a stroke on the occiput. When the rabbit is killed in this way, the respiration immediately ceases; but the action of the heart and the circulation continue, and may be supported for a considerable length of time by artificial respiration, as practised first, I believe, by FONTANA, and since by

Chirac, Mr. Brodie, M. le Gallois, and others. This mode of destroying the sensibility does not influence the result of the experiment, and has the double advantage of preventing the animal's sufferings, and his motions. Its greatest inconvenience is, that if the blow is very severe, considerable vessels are sometimes ruptured, and there is always some rupture of vessels, which of course tends to impair the vigour of the circulation.

In the present experiment, the circulation was supported by artificial respiration. The spinal marrow was laid bare from the occiput to the beginning of the dorsal vertebræ. The chest was then opened, and the heart found beating regularly, and with considerable force. The spinal marrow, as far as it had been laid bare, was now wholly removed, but without in the least affecting the action of the heart. After this, the artificial respiration being frequently discontinued, we repeatedly saw the action of the heart become languid, and increase on renewing it. The skull was then opened, and the whole of the brain removed, so that no part of the nervous system remained above the dorsal vertebræ, but without any abatement of the action of the heart, which still continued to be more or less powerful, according as we discontinued or renewed artificial respiration. This being for a considerable time discontinued, the ventricles ceased to beat about half an hour after the removal of the brain. On renewing the respiration, however, the action of the ventricles was restored. The respiration was again discontinued and renewed, with the same effects.

Exp. 2. A rabbit was made insensible by removing part of the skull, and applying opium to the brain. The spine was

then opened between the cervical and dorsal vertebræ. We then laid open the thorax, and supported the action of the heart by artificial respiration. The force with which it beat was carefully observed, and the spinal marrow destroyed by running a hot wire up and down the spine, through the opening made in it, by which the action of the heart was not at all affected.

Exp. 3. In the foregoing experiments, it may be said, there was no direct proof of the continuance of the circulation after the spinal marrow was destroyed or removed. On this account several of the following experiments were made. A rabbit, previously exhausted by dividing the eighth pair of nerves, was deprived of sensation by a blow on the occiput, and the circulation supported by artificial breathing. The carotids were seen beating near to the place where the nerves had been divided. The cervical part of the spinal marrow was then destroyed by a hot wire, after which the carotids were still found beating.

Exp. 4. In a rabbit rendered insensible by a blow on the occiput, the whole spinal marrow was destroyed by a hot wire, and the breathing artificially supported. One of the carotid arteries was then laid bare. Its beating was evident, and on dividing it, florid blood flowed from it freely.

Exp. 5. The only difference between this and the last experiment was, that artificial breathing was not performed. In both, the spinal marrow was destroyed, by introducing a wire hot enough to make a hissing noise through an opening between the cervical and dorsal vertebræ, first through the upper portion into the brain, then through the under portion to the end of the spine. On laying open one side of the neck, the

carotid artery was found beating. On dividing it, blood of a much darker colour than in the former experiment was thrown out copiously *per saltum*.

Exp. 6. A rabbit was rendered insensible by a blow on the occiput, and artificial respiration maintained. The spinal marrow from the base of the skull to the beginning of the dorsal vertebræ was removed, and a hot wire forced through the remaining part of the spine. The carotid artery was then found beating, and on dividing it florid blood rushed out with great force *per saltum*.

Exp. 7. This experiment resembled the last, except that the spinal marrow, instead of being partly removed, was wholly destroyed by a hot wire, and artificial breathing was not performed previous to opening the carotid, from which dark coloured blood flowed *per saltum*. We then inflated the lungs, and arterial blood soon began to flow copiously from the vessel, and appeared like a florid stream mixing with the dark coloured blood which had previously come from it. This experiment was repeated in the same manner, and with the same result.

Exp. 8. In this experiment the rabbit was rendered insensible, but not motionless, by the blow on the occiput, so that the breathing still continued. The spine was opened, and the spinal marrow destroyed, as in the preceding experiment. The wire was used very hot. On introducing it through the spine into the brain, the breathing immediately ceased. The femoral artery was laid bare about two or three minutes after respiration had ceased. The beating of the artery was evident. On opening it, a dark coloured blood flowed from it freely. We now had recourse to artificial respiration. When

it had been continued for about half a minute, the blood, which continued to flow copiously from the artery, became of a highly florid colour. The other femoral artery was then opened, from which florid blood also flowed freely. When about an ounce of blood had flowed from the two vessels, the inflation of the lungs was discontinued, and the blood again flowed of a dark colour. On renewing the inflation of the lungs, the blood, in less than half a minute, again became of a florid colour. It continued to flow from the femoral arteries altogether for seven minutes. Three minutes after the blood had ceased to flow from them, the artificial respiration being continued, one of the carotid arteries was opened, from which a florid blood flowed in a free stream, to the amount of a dram and a half. The flow from the carotid artery ceased in eleven minutes after the femoral artery had been opened. Most of the blood was now of course evacuated. A good deal had been lost in opening the spine, which always happens. The left auricle and ventricle were found nearly empty. The blood which remained in them was florid. The right auricle and ventricle were full of dark blood.

Exp. 9. From various trials, we found that in such experiments the circulation ceases quite as soon without, as with the destruction of the spinal marrow. Loss of blood seems to be the chief cause which destroys it. When the animal was operated upon, without being rendered insensible, pain also contributed to this effect. We frequently, after laying open the skull and spine, found the circulation lost before either the brain or spinal marrow had been disturbed. In the younger rabbit, it was lost sooner than in the older. The former seemed to die sooner from any injury, except the inter-

ruption of respiration. The circulation is particularly apt to fail, if artificial respiration is not carefully performed after the animal ceases to breathe. In making such experiments, after opening the bone, it is always necessary to ascertain whether the circulation continues, before we destroy or remove the brain or spinal marrow. As little blood is lost in this part of the operation, when the carotid arteries were beating before, we always found them beating after it. The result of this experiment is still more striking in the cold blooded animals, in which death takes place so slowly, that the circulation continues long after the total destruction of the nervous system.

Exp. 10. The brain of a frog and the spinal marrow as low as the dorsal vertebræ were laid bare. The thorax was then opened, and the heart found acting vigorously; and from the transparency of its sides, the passage of the blood through it distinctly seen. The part of the spinal marrow, which had been laid bare, was then removed, but without at all affecting either the motion of the heart, or the passage of the blood through it. The brain was then removed, with the same result.

Exp. 11. The brain and spinal marrow of a frog were wholly removed. On opening the thorax, the heart was found performing the circulation freely.

I have already had occasion to observe, that it is generally admitted that the action of the heart cannot be influenced by stimuli applied to the nervous system: and it seems almost a contradiction to suppose that it should, when we see that it cannot be influenced by the total destruction of this system. There were many reasons, however, which induced me to try

the effect on the heart of stimuli so applied to the brain and spinal marrow, as not to excite any of the muscles of voluntary motion, whose action, either by throwing more blood towards the heart, or in some other way influencing its action, prevents our judging of the effect of the stimulus.

Exp. 12. A rabbit was deprived of sensation and voluntary motion by a blow on the occiput, the action of the heart supported by artificial respiration, and the brain and cervical part of the spinal marrow laid bare. The thorax was now opened, and the action of the heart, which beat with strength and regularity, observed. Spirit of wine was then applied to the spinal marrow, and a greatly increased action of the heart was the consequence. It was afterwards applied to the brain with the same effect. The increase of motion was immediate and decided in both cases. We could not perceive that it was more in the one case than the other.

Exp. 13. The foregoing experiment was repeated, with the difference, that the whole of the spinal marrow was laid bare. The motion of the heart was nearly, if not quite, as much influenced by the application of the stimulus to the dorsal, as to the cervical portion of the spinal marrow; but it was very little influenced by its application to the lumbar portion.

Exp. 14. In this experiment, only that part of the brain which occupies the anterior part of the head was laid bare. The rabbit in other respects was prepared in the same way as in the preceding experiments. The spirit of wine applied to this part of the brain, produced as decided an effect on the motion of the heart as in those experiments. The spirit of wine was washed off, and a watery solution, first of opium, then of tobacco, applied, with the effect of an increase, but a

much less increase of the heart's action than arose from the spirit of wine. The increased action was greater from the opium, than from the tobacco. The first effect of both was soon succeeded by a more languid action of the heart than that which preceded their application to the brain. This effect was greatest, and came on soonest when the tobacco was used, and we always, for we frequently repeated the experiment, saw an evident increase in the action of the heart, when we washed off the tobacco. We could also perceive this, though in a less degree, when the opium was washed off. Little or none of this debilitating effect was observed when the spirit of wine was used. After its stimulating effect had subsided, the action of the heart only returned to about the same degree as before the application of the stimulus.

Exp. 15. The foregoing experiment was repeated on an animal of cold blood. Mr. HASTINGS had found, that immersing the hind legs of a frog in tincture of opium, in less than a minute, deprives it of sensibility. This does not arise from any action of the opium; a watery solution of opium, we found, however strong, does not produce the effect. It is immediately produced by simple spirit of wine, and arises from the action of the spirit on the nerves of the part to which it is applied, for it takes place quite as readily as in the healthy frog, after a ligature has been thrown round all the vessels attached to the heart. It is remarkable, that if simple spirit of wine is used, the animal expresses severe pain, if tincture of opium, very little. I have already mentioned the reason why it is necessary, in order to judge of the result of this experiment, that the animal should be rendered insensible. (*Exp.* 11.)

Having thus deprived a frog of sensibility, we laid bare the

brain and spinal marrow, and opened the chest. The heart was found contracting with vigour. Spirit of wine was then applied to the spinal marrow, with an immediate and evident increase of the action of the heart. It was then applied to the brain with the same effect. Watery solutions of opium and tobacco were also applied to both, with precisely the same effect as in the rabbit. The increase of action from the opium and tobacco was much less than from the spirit of wine, and was soon followed by a great diminution of action. The increase of action was least, and the diminution greatest from tobacco. On washing off the opium and tobacco with a wet sponge, the heart immediately beat more strongly. The different parts of this experiment were frequently repeated with the same result. It is remarkable that we could affect the motion of the heart by stimuli applied to the brain and spinal marrow, after they had ceased to produce any effect on the muscles of voluntary motion through the medium of the nervous system.

Exp. 16. This experiment only differed from the last in the cervical part of the spinal marrow and lower part of the brain being removed, and the stimuli applied only to that part of the brain which lies between the eyes of the frog. Spirit of wine, opium, and tobacco, thus applied, affected the motion of the heart quite as much, and precisely in the same way, as when they were applied to the entire brain and spinal marrow. When opium and tobacco were applied to the lower part of the spinal marrow, the motion of the heart appeared to be hardly at all affected by them. It was evidently increased when spirit of wine was applied to the same part.

We found in the foregoing experiments, that considerable

pressure, either on the brain or spinal marrow, produced little or no effect on the action of the heart. Its action could be influenced by stimuli applied to the brain and spinal marrow long after the circulation had ceased.

The peristaltic motion of the intestines, as far as we could judge from the following experiments, obeys the same laws as the action of the heart.

Exp. 17. A rabbit was deprived of sensibility by a blow on the occiput. The whole of the spinal marrow was then destroyed by a hot wire. On opening the abdomen, we found the peristaltic motion of the stomach and small and great intestines quite as strong as when the nervous system is entire, as we ascertained by exposing the abdominal viscera of other rabbits. In another experiment, the spinal marrow was wholly removed, without at all affecting this motion. The removal of the brain, we found, produces as little effect upon it, as that of the spinal marrow. When both were removed at the same time, it remained unaffected. It continues till the intestines become cold, so that when the portions exposed to the air have lost their power, the motion of the parts beneath still remains.

We endeavoured to ascertain how far this motion is influenced by stimuli applied to the brain and spinal marrow, but from its nature it is in every way so irregular, that no certain result can be obtained. It often appeared to us, that spirit of wine applied to the brain and spinal marrow increased it.

The admission of air into the cavity of the abdomen throws the bowels into strong spasmodic action, which alone would obscure any effect that can be supposed to arise from stimulating the brain. To remove this cause of failure, the abdomen

was opened under tepid water; but this was found to excite even stronger spasms than the air had done.

What are the simple results of the foregoing experiments? The first set prove, that the power of the heart is independent of the brain and spinal marrow, for we find that it continues to perform its function after they are destroyed or removed, and that their removal is not attended with any immediate effect on its motions. The second set prove, that the action of the heart may be influenced by agents applied to any considerable portion either of the brain or spinal marrow. It is as readily influenced by agents applied to the anterior part of the brain, as by those applied to the cervical part of the spinal marrow. This is what we should expect when we trace the various origins of its nerves.

If it be said that the results of these experiments imply a contradiction, that we cannot suppose the power of the heart to be wholly independent of the brain and spinal marrow, and yet influenced by stimuli applied to them, the reply is, that such are the facts, of the truth of which any one may easily satisfy himself. Daily occurrences correspond with these facts. We rarely see the action of the heart destroyed by injuries of the brain and spinal marrow, unless they are such as interrupt respiration; yet its action is constantly influenced by affections of the mind.

On a closer examination of the phenomena of the nervous system, we shall find other similar difficulties. The experiments of M. LE GALLOIS prove, in the most satisfactory manner, that a principal function of the spinal marrow is to excite the muscles of voluntary motion, and that it can perform this office independently of the brain. It performs it

after the brain is wholly removed, and its powers seem not at all immediately impaired by the removal of the brain; yet we constantly see injuries of the brain impairing the functions of the spinal marrow. We may wholly remove the brain, and the animal performs the various motions of its limbs as well as before its removal. Yet an injury of the brain often produces complete hæmiplegia, nay often instantly destroys every function of the system. Of this apparent inconsistency, M. LE GALLOIS justly remarks, that two facts well ascertained, however inconsistent they may seem, do not overturn each other, but only prove the imperfection of our knowledge.

Whichever of the disputed opinions respecting the functions of the nervous system we adopt, the foregoing phenomena seem to imply a contradiction; for an explanation of them, therefore, we must recur to principles different from those hitherto assumed. The following experiments point out still another instance of this apparent contradiction, and seem to suggest the principle on which the whole depends.

Exp. 18. By applying strong stimuli to the spinal marrow of a frog, strong and repeated contractions were excited in the muscles of the hind limbs, as long as the stimuli would produce the effect. On examining the state of the muscles of these limbs, I found them wholly deprived of their excitability. Now it is well known, that although all the nerves supplying the limbs of a frog be divided, and cut out close to the place where they enter the muscles, the latter still retain their excitability, which appears to be not at all less than while the nerves are entire. Lest it may be supposed that the nervous influence, which was exhausted in this experiment by stimulating the spinal marrow, still remains in

the muscles after the nerves are divided, and thus preserves their excitability, the following experiment was made.

Exp. 19. All the nerves supplying one of the hind limbs of a frog were divided, so that it became completely paralytic. The skin was removed from the muscles of the leg, and salt sprinkled upon them, which, being renewed from time to time, excited contractions in them for twelve minutes; at the end of this time they were found no farther capable of being excited. The corresponding muscles of the other limb, in which the nerves were entire, and of which consequently the animal had a perfect command, were then laid bare, and the salt applied to them in the same way. In ten minutes they ceased to produce any contractions, and the animal had lost the command of them. The nerves of this limb were now divided, as those of the other had been, but the excitability of the muscles to which the salt had been applied was gone. Its application excited no contraction in them. It sometimes happens, while the nerves of the limb are entire, that the voluntary efforts of the animal prevent the contractions usually excited by the application of salt. This experiment was repeated in the same manner, and with a similar result. After the experiment, the muscles of the thighs in both limbs were found to contract forcibly on the application of salt. It excited equally strong contractions on both sides.

It is remarkable, that in this experiment, the excitability of the muscles whose nerves were entire, was soonest exhausted. In the repetition of the experiment, this was the case to a still greater degree, the muscles, whose nerves were entire, losing their excitability in about one half of the time required for exhausting the other.

From this experiment it is evident, that the nervous influence, so far from having a power of preserving the excitability of the muscles, exhausts it like other stimuli. The excitability therefore is a property of the muscle itself. Yet we have just seen, that it may be wholly destroyed by changes induced on the nervous system. On the same principle we explain the seeming contradiction respecting the action of the heart. We have seen that its power exists as independently of the brain and spinal marrow, as the action of the first muscles to which the salt was applied, whose nerves had been divided; but, while the brain and spinal marrow retain their functions, and the connection of nerves is entire, the heart, as well as the muscles of voluntary motion, may be influenced by agents acting through the nervous system. It is not difficult to account for the latter being more copiously supplied with nerves than the heart, because all the stimuli which affect them, act through their nerves, while the heart is only now and then influenced through its nerves, its usual stimulus being as immediately applied to it, as the salt was to the muscles of the limb in the above experiment, and acting as independently of the nervous system. We do not surely in all this see any difference in the nature of the muscular power of the heart, and that of the muscles of voluntary motion, except their being fitted to obey different stimuli, a difference which we find in the two sides of the heart itself.

It may here be objected, that in apoplexy the power of the muscles of voluntary motion is lost, while that of the heart is little or not at all impaired. Were such the fact, this objection would be unanswerable; but I have repeatedly examined the state of the muscles of voluntary motion in apoplexy,

both in the warm and cold blooded animals, and found their excitability unimpaired. It is not their power, but the stimulus which excites them, that is lost in apoplexy. In this disease, the heart continues to contract, because its stimulus is still supplied; the muscles of voluntary motion cease to contract, because their stimulus is withdrawn.

By the foregoing experiments we arrive at the conclusion of HALLER, that the heart and other muscles possess an excitability independent of the nervous system; but we are carried a step farther, and taught that they are all equally capable of being stimulated through this system, by which the great objections to HALLER'S doctrine are removed. We may, I think, trace the subject still farther. It has been shown by direct experiment by M. LE GALLOIS, that the spinal marrow is capable of performing its functions independently of the brain, yet, as has just been observed, the spinal marrow may be influenced through the brain. Thus the excitability of the spinal marrow bears the same relation to the brain, which that of the muscles bears to the spinal marrow and its nerves, and I would add all nerves distributed to muscles, some of which arise from the brain, but seem to bear precisely the same relation to the sensorium with those which arise from the spinal marrow. Even M. LE GALLOIS, although his experiments lead to an opposite conclusion, observes, that the brain seems to act on the spinal marrow as the latter does on the parts it animates. We know the peculiar office of the brain, by observing what functions are lost by its removal, the sensorial functions. The nervous, then, obeys the sensorial system, in the same way in which the muscular obeys the nervous system, but as the muscular system has an existence independent of the

nervous, so has the nervous, independent of the sensorial system.

What is here said is finely illustrated by reviewing the various classes of animals. In the lowest class we find only the muscular system, which exists without either nervous system or sensorium. In the next class we find the muscular and nervous systems, which exist without sensorium. In the most perfect animals, we find the three vital powers combined, each having an existence not immediately depending on the others, but all so connected, that none can exist long without the others. The nature of this connection is obvious, when we consider that all are supported by the circulation, which depends for its immediate support on the muscular system, and cannot long exist without respiration, and that this depends not on the sensorium, but, as M. LE GALLOIS has satisfactorily proved, on the nervous system, which system is under the immediate influence of the sensorium, directing, but not producing, its various movements; and such is the power of the sensorium over the nervous system, that its affections may, through this system, at once destroy every function of life. Thus joy and other strong passions have killed more speedily than suffocation can, and therefore otherwise than through the destruction of respiration.

Exp. 20. All that has been said of the vital power of the heart is strikingly confirmed by the following experiments. If the head and spine of a frog be removed, the heart continues to perform its function perfectly for many hours, nor does it seem at all immediately affected by their removal. But we find the effect very different when the most sudden and powerful agent is applied to them. If they are destroyed by being cut

to pieces, or even by a hot wire, the heart after their destruction beats just as before it. But if either the brain or spinal marrow be instantly crushed, the heart immediately feels the shock.

The thorax of a large frog was laid open, and the motion of the heart observed, which performed the circulation perfectly, and with great force. The brain was then crushed by the blow of a hammer. The heart immediately performed a few quick and weak contractions. It then lay quite still for about half a minute. After this, its beating returned, but it supported the circulation very imperfectly. In ten minutes its vigour was so far restored that it again performed the circulation with freedom, but with less force than before the destruction of the brain. An instrument was then introduced under the heart, and after ascertaining that this had produced no change on its action, the spinal marrow was crushed by one blow, as the brain had been. The heart again beat quickly and feebly for a few seconds, and then seemed wholly to have lost its power. In about half a minute it again began to beat, and in a few minutes acquired considerable power, and again supported the circulation. It beat more feebly, however, than before the spinal marrow was destroyed. It ceased to beat in about an hour and a half after the brain had been destroyed. In another frog, after the brain and spinal marrow had been wholly removed, the heart beat nine hours, gradually becoming more languid.

In this experiment we see that the heart not only retains its power long after the brain and spinal marrow are removed, but that if they are destroyed in such a way as to impair and almost destroy the action of the heart, it can recover the power of performing its function, after they no longer exist; pre-

cisely as a muscle of voluntary motion will by rest recover its excitability, although all its nerves are divided, if its circulation continues.

M. Bichat (*Récherches Phys. sur la vie et la mort.*) has shown that in a frog the circulation continues in the capillaries after the heart no longer propels the blood.

Exp. 91. The foregoing experiment cannot be performed in the same way on warm-blooded animals, but it may be performed in a way equally satisfactory. In two rabbits the brain was crushed by a blow. In both the heart immediately beat with an extremely feeble and fluttering motion. The anterior part of the brain only was crushed in another rabbit, with the same result. A strong ligature was thrown round the neck of a fourth rabbit, and at the moment it was tightened, the head was cut off. The bleeding was restrained by the ligature, except from the vessels defended by the bone. General spasms made the body hard for the space of between one and two minutes, so that the beating of the heart could not be felt. At the end of this time, the heart was felt through the side, both by Mr. Hastings and myself, beating regularly, and not more quickly than in health. All the rabbits used in this experiment were of the same age.

Exp. 92. The following experiment is still more conclusive. The anterior part of the brain of a rabbit was crushed by a blow. The side was rendered hard by spasm for about half a minute. Neither during this, nor after it, could I perceive any motion of the heart by applying the hand to the side. The head was then cut off, about three quarters of a minute after the brain had been crushed. No blood spouted out, and very little ran from the vessels. A strong ligature

was passed round the neck of another rabbit of the same age. It was suddenly tightened, and the head cut off. In this instance little spasm took place, and the heart was found beating regularly under the finger for about three quarters of a minute. At the end of this time, the ligature was slackened, and the blood spouted out to the distance of three feet, and continued to spout out with great force, till nearly the whole blood was evacuated.

Exp. 28. From the strength of the spine of a rabbit, and the situation of the neighbouring parts, it is impossible to crush it, without directly influencing the state of the heart by the blow. We opened it between the cervical and dorsal vertebræ, and suddenly forced a steel rod through the cervical part. As in the experiments of M. LE GALLOIS, the action of the heart was immediately debilitated. In the preceding experiments, the reader has seen, we repeatedly, slowly destroyed, or removed entirely, both the cervical and other portions of the spinal marrow, without at all influencing the action of the heart.

These experiments point out an easy solution of the difficulties mentioned by M. LE GALLOIS in the 119th and following pages of his Treatise. When the whole spinal marrow was destroyed by small portions at a time, comparatively little effect was produced on the heart; but when a considerable part of it was crushed at once, the power of the heart was so impaired, that circulation ceased. So in other cases, where the injury was inflicted slowly, and where it was inflicted suddenly, the result was found to be different.

Thus he observes, that if the spinal marrow be divided near the occiput, and a certain part of it immediately destroyed,

circulation ceases. If some time intervene between the division and the destruction of precisely the same part, the circulation is not interrupted.

M. LE GALLOIS' explanation of these facts cannot surely be admitted, and indeed is inconsistent with his own positions. He found, that confining the circulation to a less extent, by throwing ligatures round the large vessels at some distance from the heart, enables this organ to support the circulation under circumstances where it would otherwise have failed. Writers on midwifery have, on the same principle, recommended compressing the arteries of the limbs when the powers of the heart are much weakened by hemorrhagy. From this experiment, compared with others, M. LE GALLOIS infers, that when the spinal marrow is destroyed by small portions, the circulation, in the parts corresponding to these portions, being impeded, the effect is similar to that produced by the ligatures. Now, although it were ascertained that the circulation is impeded in any part by destroying the portion of the spinal marrow from which it is supplied with nerves, which I think may easily be shown not to be the case, this explanation would still be in opposition to M. LE GALLOIS' fundamental position: "Que la quantité, que le contingent de forces, que chaque "portion de moëlle fournit à cet organe, égale pour le moins "celles dont il auroit strictement besoin pour entretenir la "circulation dans les seules parties correspondantes à cette "portion." When the ligatures were thrown around the vessels, the heart was deprived of none of its supposed nervous influence. When, on the contrary, portions of the spinal marrow were successively destroyed, as far as this is supposed to confine the circulation, it must also, according to M. LE

GALLOIS, occasion a loss of power in the heart. He remarks that till the above explanation occurred to him, he had resolved to abandon this part of the inquiry. "Après bien "des efforts inutiles pour porter la lumière dans cette téné- "breuse question, je pris le parti de l'abandonner, non sans "regret d'y avoir sacrifié un grand nombre d'animaux, et "perdu beaucoup de temps." Just before, he observes, "En "un mot, j'eus presque autant de résultats différens que d'ex- "périences." This may be easily accounted for, as he was not aware that the rapidity with which any portion of the spinal marrow is destroyed, influences the result. We also see why the sudden destruction of one half of the spinal marrow, after it had been divided, not only brought death to that part of the animal to which it belonged, but to the other also; a fact which seems in direct opposition to M. LE GALLOIS' explanation of that we have just been considering.

In M. LE GALLOIS' experiments, the spinal marrow was always crushed by a stilet, of precisely the same dimensions with the cavity of the spine. In the foregoing experiments, the spinal marrow was either removed or destroyed by a comparatively small wire moved about in it till all its functions ceased. The reader will easily understand, from what has been said, why this apparently slight circumstance occasions so essential a difference in the result of the experiments. We have just seen the difference of the result when any portion of the spinal marrow is successively destroyed by parts, or crushed at once, and when the brain is crushed at once or wholly removed.

We have every reason to believe, from the experiments which have been related, that the peristaltic motion of the

bowels obeys the same laws as the action of the heart. It appears from those experiments, that this motion is wholly independent of the nervous system. It continues till the parts become cold after the brain and spinal marrow are removed. I have already mentioned the circumstances which prevented our positively ascertaining, whether it is influenced by stimuli applied to the brain and spinal marrow, (Exp. 17.) but we know that the action of the bowels is frequently influenced by affections of the mind.

From the whole of the foregoing experiments and observations, it appears,

1. That the muscles of involuntary motion obey the same laws with those of voluntary motion. Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, and 17, compared with Exp. 18, and 19; see also observations under Exp. 19.

2. That the apparent difference in the nature of these muscles, arises from their being under the influence of different stimuli; see observations under Exp. 19.

3. That they are both capable of being stimulated through the nervous system. Exp. 12, 13, 14, 15, 16.

4. That the power of both is independent of the nervous system. Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 17, 18, and 19.

5. That what is called the nervous system consists of two parts, whose existence is not immediately dependent on each other; the one performing the sensorial functions, the other conveying impressions to and from the sensorium, and, without bestowing any power on the muscular system, acting as a stimulus to it. See the observations under Exp. 19. See also Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 18, 19.

6. That there is therefore in the most perfect animals a combination of three distinct vital powers, not immediately depending on each other; one of the muscular system, one of the nervous system properly so called, and one of the sensorial system. See observations under Exp. 19.

7. That the muscular system, though independent of the nervous system, is so influenced by it, that the power of the former may even be destroyed through the nervous system. Exp. 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, compared with Exp. 18, 20, and 23.

8. That both the muscular and nervous systems, though independent of the sensorial system, are so influenced by it, that they may even be destroyed through it. Exp. 8, 10, 11, 17, and two last paragraphs under Exp. 19, compared with Exp. 20, 21, 22.

9. That although in the less perfect animals we find the muscular life existing alone, and the muscular and nervous existing without the sensorial life; in the more perfect animals they are so connected, that none can exist long without the others. See the last paragraph under Exp. 19.

10. That nutrition, circulation, and respiration, are the means by which they are so connected.

Worcester, August 16th, 1814.

VII. *Experiments to ascertain the influence of the spinal marrow on the action of the heart in fishes.* By Mr. William Clift. *Communicated by Sir* Everard Home, *Bart. V. P. R. S.*

Read February 16, 1815.

As the experiments of M. Gallois, which led him to conclude, that the action of the heart is dependent upon the spinal marrow, were principally made upon quadrupeds, in which death is so readily produced, when the vital organs are injured, or any one of them destroyed; I thought by repeating those experiments upon fishes, which are much more tenacious of life, and whose mode of respiration is of a more simple nature, the truth or fallacy of his conclusions might be ascertained.

I was led to select the carp for this purpose, having observed that a carp after the head was cut off, and the heart had been removed for above four hours, and the fish was considered to have been long dead, upon being put into hot water, leaped out of the vessel with a degree of vigour totally unexpected, being equal to the struggles of a living fish.

I shall not take up the time of the Society, by a detail of all the experiments I made, but shall only select those which bear upon this particular subject.

Exp. 1. Two carp of nearly equal size, had their hearts exposed, by opening into the pericardium. In one of them, the heart on exposure pulsated twenty times in a minute, but soon after, only twelve. The fish was put into river water,

in which it swam, with the tail, fins, and gills in full action; in forty minutes the fish turned upon its side, the action of the heart weak, the frequency of pulsations the same; the fins ceased to act, the tail continued to act feebly, the gills strongly.

In an hour, the action of the heart was weaker, the frequency of pulsations the same.

In two hours, the action of the heart and gills was not perceptible in the water, but when taken out and examined, the gills had a feeble action by irregular jerks; the pulsations of the heart were very weak, and rather more frequent.

In three hours, the heart and gills had ceased to act, and the muscles of the body did not contract when stimulus was applied to them.

In the other carp, the heart pulsated eight times in a minute. The fish was laid upon a moist leaden tray. In one hour the pulsations were ten in a minute; in an hour and half, twelve, the fins and tail in full motion. In two hours, the pulsations were a little weaker, but of the same frequency. In three hours and forty minutes the action of the heart ceased. The gill covers acted fifteen minutes longer.

Exp. 2. Having exposed the heart of a carp as in the former experiment, the pulsations were found to be eight in a minute. In eleven minutes, a red hot wire was passed from the tail to the occiput, so as to destroy the spinal marrow; the action of the heart was immediately quickened for three beats; then a long pause, after which the pulsations were the same as before. All action ceased in the muscles behind the pectoral fins, and those muscles did not contract, when stimulus was applied to them.

In one hour from the laying open the pericardium, and five minutes from the passing of the wire, the pulsations had the same frequency.

In twenty minutes after passing the wire, the pulsations were strong, and fifteen in a minute.

In forty-five minutes, the pulsations were twelve in a minute, exactly corresponding with those of the heart of the carp laid on the wet tray, in which the spinal marrow remained entire.

The brain was now exposed, the pulsations became fifteen in a minute, but in five minutes were only twelve. The brain was then extracted, the pulsations of the heart were not sensibly affected either in strength or frequency. The gills and mouth had no longer the least degree of action. In two hours from the beginning of the experiment, the pulsations were fifteen in a minute.

Turning the fish always accelerated the action of the heart a little.

In three hours, the pulsations were the same.

In four hours, they were twelve in a minute.

In five hours, they varied from twelve to six in a minute.

In six hours, they were six in a minute.

In seven hours, nine in a minute.

From this time the action of the heart was very slow and weak: In eight hours and a half, once in a minute.

In eleven hours and forty minutes, they ceased entirely.

Exp. 8. A carp had the heart exposed, by laying open the pericardium: The pulsations were twenty in a minute, but soon were only twelve.

In forty minutes, the spinal marrow at the occiput was cut

through, which increased the action of the heart for three or four beats, which were very violent, and at the rate of twenty in a minute; the pulsations were then twelve as before.

In fifty minutes, a red hot iron wire was passed from the tail to the occiput, and produced strong action in the tail; but from this time, there was no action in the muscles of the body or tail. The pulsations of the heart became a little slower. In sixty minutes they were strong, and twelve in a minute.

The brain was now broke down by a small flat pointed instrument; the pulsations of the heart became twenty in a minute. The gills and mouth from this time ceased to act. The heart went on pulsating with the same frequency as before, but weaker, for two hours, and then gradually ceased; the auricle contracting for more than a quarter of an hour after the action of the ventricle had ceased.

Exp. 4. A weakly carp of nearly the same length with those employed for the other experiments, which was fifteen inches, had the spinal marrow exposed near the base of the tail, and a red-hot iron wire passed along the vertebral canal. All action of the body and gills immediately ceased.

On removing a portion of the skull to expose the brain, the end of the wire was found in the skull, but the brain uninjured. The brain was then entirely removed: no motion was produced in any part of the body or gills.

The body was placed in a wet towel for three hours. The heart was then exposed, its action was strong and distinct in both the auricle and ventricle, at the rate of twenty beats in a minute, but after five pulsations, at the rate of twelve, at which it continued.

At three hours and a half, the action of the heart was weaker

and slower, there being an interval of one second between the contraction of the auricle and ventricle. From the time of exposing the heart no action was perceptible in the branchial artery; it remained of a blue colour, and turgid with blood from its first exposure.

At three hours and three quarters, the pulsations of the heart were only nine in a minute. The interval between the contraction of the auricle and ventricle three seconds.

At four hours, the pulsations were seven in a minute, the interval between the contraction of the auricle and ventricle four seconds.

At four hours and a quarter, the pulsations were seven in a minute; the interval between the contraction of the auricle and ventricle five seconds.

At four hours and a half, seven in a minute; the interval between the contraction of the auricle and ventricle six seconds.

At four hours and three quarters, seven in a minute; the auricle and ventricle acting together.

At five hours, seven in a minute, the interval between the contraction of the auricle and ventricle, one second and a half.

At six hours, the contraction of the auricle seven in a minute, the action of the ventricle hardly perceptible.

At six hours and a quarter, the contractions of the auricle weak: seven in a minute.

At six hours and a half, the auricle ceased to contract; and after this time, no stimulus produced the smallest action in any part of the heart. This experiment was suggested by a notice taken from Dr. Wilson Philip's paper, published in

the Edinburgh Medical and Chirurgical Journal for January last, and made many months after the other experiments.

From these experiments we have the following results:

1. That the muscles of the body of a carp four hours after the brain and heart are removed, can be thrown into powerful action.

2. That the moment the spinal marrow is destroyed, these muscles lose all power of action.

3. That when water is admitted into the pericardium, and the fish allowed to swim about, the action of the heart ceases sooner than when that organ is exposed to air, and the fish kept quiet.

4. That whether the heart is exposed or not, its action continues long after the spinal marrow and brain are destroyed, and still longer when the brain is removed without injury to its substance.

5. That the action of the heart is accelerated for a few beats, by exposure of that organ; by exposure of the brain; injury to the brain; destruction of the spinal marrow while connected with the brain; by the connection between the brain and spinal marrow being cut off: while removing the whole brain produces no sensible effect upon the heart's action, and destroying the spinal marrow after it is separated from the brain renders the action of the heart slower for a few beats.

VIII. *Some experiments and observations on the colours used in painting by the Ancients.* *By Sir* Humphry Davy, *LL. D. F. R. S.*

Read February 23, 1815.

I. *Introduction.*

THE importance the Greeks attached to pictures, the estimation in which their great painters were held, the high prices paid for their most celebrated productions, and the emulation existing between different states with regard to the possession of them, prove that painting was one of the arts most cultivated in ancient Greece; the mutilated remains of the Greek statues, notwithstanding the efforts of modern artists during three centuries of civilization, are still contemplated as the models of perfection in sculpture, and we have no reason for supposing an inferior degree of excellence in the sister art, amongst a people to whom genius and taste were a kind of birthright, and who possessed a perception, which seemed almost instinctive, of the dignified, the beautiful, and the sublime.

The works of the great masters of Greece are unfortunately entirely lost. They disappeared from their native country during the wars waged by the Romans with the successors of Alexander, and the later Greek republics; and were destroyed either by accident, by time, or by barbarian conquerors at the period of the decline and fall of the Roman Empire.

The subjects of many of these pictures are described in

ancient authors, and some idea of the manner and style of the Greek artists may be gained from the designs on the vases, improperly called Etruscan, which were executed by artists of Magna Græcia, and many of which are probably copies from celebrated works: and some faint notion of their execution and colouring may be gained from the paintings in fresco found at Rome, Herculaneum, and Pompeii.

These paintings, it is true, are not properly Greek, yet whatever may be said of the early existence of painting in Italy as a native art, we are certain that at the period when Rome was the metropolis of the world, the fine arts were cultivated in that city exclusively by Greek artists, or by artists of the Greek schools. By comparing the descriptions of VITRUVIUS* and PLINY with those of THEOPHRASTUS,† we learn that the same materials for colouring were employed at Rome and at Athens; and of thirty great painters that Pliny mentions whose works were known to the Romans, two only are expressly mentioned as born in Italy, and the rest were Greeks. Ornamental fresco painting was indeed generally exercised by inferior artists; and the designs on the walls of the houses of Herculaneum and Pompeii, towns of the third or fourth order, can hardly be supposed to offer fair specimens of excellence, even in this department of the art: but in Rome, in the time of her full glory, and in the ornaments of the imperial palace of the first Cæsars, all the resources of the distinguished artists of that age were probably employed. PLINY names CORNELIUS PINUS and ACCIUS PRISCUS as the two artists of the greatest merit in his own time, and states that they painted the Temple of Honour and Virtue,‡ "Imperatori

* De Architectura, Lib. vii. Cap. 5. † De Lapidibus.

‡ Plin. Nat. Hist. Lib. xxxv. Cap. 37.

Vespasiano Augusto restituenti," and it is not improbable, that these artists had a share in executing, or directing the execution of the paintings and ornaments in the baths of Titus; and at this period the works of Zeuxis, Parrhasius, Timanthes, Apelles, and Protagoras were exhibited in Rome, and must have guided the taste of the artists. The decorations of the baths were intended to be seen by torch light, and many of them at a considerable elevation, so that the colours were brilliant and the contrast strong; yet still these works are regarded by connoisseurs as performances of considerable excellence: the minor ornaments of them have led to the foundation of a style in painting which might with much more propriety be called Romanesque than Arabesque: and no greater eulogy can be bestowed upon them than the use to which they have been applied by the greatest painter of modern times, in his exquisite performances in the Vatican. In these and in other works of the same age, the effect of the ancient models is obvious; and the various copies and imitations that have been made of these remains of antiquity have transferred their spirit into modern art, and left little to be desired as to those results which the skill of the painter can command. There remains, however, another use to which they may be applied, that of making us acquainted with the *nature* and *chemical composition* of the colours used by the Greek and Roman artists. The works of THEOPHRASTUS, DIOSCORIDES, VITRUVIUS, and PLINY, contain descriptions of the substances used by the ancients as pigments; but hitherto, I believe, no experimental attempt has been made to identify them, or to imitate such of them as are peculiar.* In the

* In the 70th Volume of the Annales de Chimie, page 22, M. CHAPTAL has

following pages I shall have the honor of offering to the Society an investigation of this subject. My experiments have been made upon colours found in the baths of Titus, and the ruins called the baths of Livia, and in the remains of other palaces and baths of ancient Rome, and in the ruins of Pompeii. By the kindness of my friend, the celebrated CANOVA, who is charged with the care of the works connected with ancient art in Rome, I have been enabled to select, with my own hands, specimens of the different pigments that have been found in vases discovered in the excavations, lately made beneath the ruins of the palace of Titus, and to compare them with the colours fixed on the walls or detached in fragments of stucco: and Signor NELLI, the proprietor of the Nozze Aldobrandine, with great liberality permitted me to make such experiments upon the colours of this celebrated picture, as were necessary to determine their nature. When the preservation of a work of art was concerned, I made my researches upon mere atoms of the colour, taken from a place where the loss was imperceptible: and without having injured any of the precious remains of antiquity, I flatter myself, I shall be able to give some information not without interest to scientific men as well as to artists, and not wholly devoid of practical applications.

published a paper on seven colours found in a colour shop at Pompeii. Four of these he found to be natural colours, ochres, a specimen of Verona green, and one of pumice stone. Two of them were blues, which he considers as compounds of alumine and lime with oxide of copper, and the last a pale rose colour, which he regards as analogous to the lake formed by fixing the colouring matter of madder upon alumine. I shall again refer to the observations of M. CHAPTAL in the course of this paper. It will be found on perusal, that they do not supersede the enquiry mentioned in the text.

II. *Of the red colours of the Ancients.*

Amongst the substances found in a large earthen vase filled with mixtures of different colours with clay and chalk, found about two years ago in a chamber at that time opened in the baths of Titus, are three different kinds of red. One bright and approaching to orange, another dull red, a third a purplish red.* On exposing the bright red to the flame of alcohol, it became darker red, and on increasing the heat by a blowpipe, it fused into a mass having the appearance of litharge, and which was proved to be this substance by the action of sulphuric and muriatic acids. This colour is consequently minium, or the red oxide of lead.

On exposing the dull red to heat, it became black, but on cooling recovered its former tint. When heated in a glass tube it afforded no volatile matter condensible by cold but water. Acted on by muriatic acid, it rendered it yellow, and the acid, after being heated upon it, yielded an orange coloured precipitate to ammonia. When fused with hydrate of potassa, the colour rendered it yellow; and the mixture acted on by nitric acid afforded silica and orange oxide of iron. It is evident from these results that the dull red colour is an iron ochre.

The purplish red submitted to experiments, exhibited similar phenomena, and proved to be an ochre of a different tint.

In examining the fresco paintings in the baths of Titus, I found that these colours had been all of them used, the ochres particularly, in the shades of the figures, and the minium in the ornaments on the borders.

I found another red on the walls, of a tint different from

* Nearly of the same tint as prussiate of copper.

those in the vase and much brighter, and which had been employed in various apartments, and formed the basis of the colouring of the niche and other parts of the chamber in which the Laocoon is said to have been found. On scraping a little of this colour from the wall, and submitting it to chemical tests, it proved to be vermilion or cinnabar, and on heating it with iron filings, running quicksilver was procured from it.

I found the same colour on some fragments of ancient stucco in a vineyard near the pyramidal monument of CAIUS CESTIUS.

In the Nozze Aldobrandine, the reds are all ochres. I tried on these reds the action of acids, of alkalies, and of chlorine, but could discover no traces either of minium or vermilion in this picture.

Minium was known to the Greeks under the name of *σανδαράχη*,* and to the Romans under that of cerussa usta. It is said, by PLINY,† to have been discovered accidentally by means of a fire that took place at the Piræeus at Athens. Some ceruse which had been exposed to this fire was found converted into minium, and the process was artificially imitated: and he states that it was first used as a pigment by NICIAS.‡

Several red earths used in painting are described by THEOPHRASTUS, VITRUVIUS,§ and PLINY. The Sinopian earth, the Armenian earth, and the African ochre, which had its red colour produced by calcination.

Cinnabar or vermilion was called by the Greeks *μινίον*,‖ and by the Romans minium. It is said by THEOPHRASTUS¶ to have been discovered by CALLIAS, an Athenian, ninety years before PRAXIBULUS, and in the 349th year of Rome, and was

* Dioscorides, Lib. v. 122.
† Lib. xxxv. Cap. 20.
‡ Pliny, Lib. xxxv. Cap. 20. Dioscorides, Lib. v. Cap. 109.
§ De Architectura, Lib. vii. Cap. 7.
¶ De Lapid. Cap. 104.

prepared by washing the ores of quicksilver. According to PLINY,* who quotes VERRIUS, it was a colour held in great esteem in Rome at the time of the Republic; on great festivals it was used for painting the face of Jupiter Capitolinus, and likewise for colouring the body of the Victor in the triumphal processions, "sic Camillum triumphasse."† PLINY mentions that even in his time vermilion was always placed at triumphal feasts amongst the precious ointments; and that the first occupation of new censors of the Capitol was to fill the place of vermilion painter to Jupiter.

Vermilion was always a very dear colour amongst the Romans; and we are informed by PLINY that to prevent the price from being excessive, it was fixed by the government. The circumstance of the chambers in the baths of Titus being covered with it, affords proof in favour of their being intended for imperial use; and we are expressly informed by the author I have just quoted, that the Laocoon, in his time, was in the palace of Titus;‡ and the taste of the ancients in selecting a colour to give full effect to their master pieces of sculpture was similar to that of a late celebrated English connoisseur.

PLINY describes a second or inferior sort of vermilion formed by calcining stone found in veins of lead. It is evident, that this substance was the same as our minium, and the Roman cerussa usta, and the stones alluded to by PLINY must have been carbonate of lead: and he states distinctly, that it is a substance which becomes red only when burnt.

* Lib. xxxiii. Cap. 36. Nunc inter pigmenta magnæ auctoritatis, et quondam apud Romanos non solùm maximæ, sed etiam sacræ. † Ibid.

‡ Lib. xxxvi. Cap. 4. Sicut in Laocoonte, qui est in Titi Imperatoris domo, opus omnibus et picturæ et statuariæ artis præponendum.

III. *Of the yellows of the ancients.*

A large earthen pot found in one of the chambers of the baths of Titus contains a quantity of a *yellow paint*, which, submitted to chemical examination, proved to be a mixture of yellow ochre with chalk or carbonate of lime.

This colour is used in considerable quantities in different parts of the baths; but principally in the least ornamented chambers, and in those which were probably intended for the use of the domestics. In the vase to which I alluded in the last section, I found three different yellows; two of them proved to be yellow ochres mixed with different quantities of chalk, and the third a yellow ochre mixed with red oxide of lead, or minium.

The ancients procured their yellow ochre* from different parts of the world, but the most esteemed, as we are informed by PLINY, was the Athenian ochre; and it is stated by VITRUVIUS, that in his time the mine which produced this substance was no longer worked.

The ancients had two other colours which were orange or yellow; the auripigmentum, or ἀρσενικὸν, said to approach to gold in its colour, and which is described by VITRUVIUS† as found native in Pontus, and which is evidently sulphuret of arsenic; and a *pale* sandarach, said by PLINY to have been found in gold and silver mines, and which was imitated at Rome by a partial calcination of ceruse, and which must have been massicot, or the yellow oxide of lead mixed with minium. That there was a colour called by the Romans sandarach, different from pure minium, is evident from what

* ὤχρα, Theophrastus de Lapidibus. † Vitruvius, Lib. vii.

PLINY says, namely, that the palest kind of orpiment resembles sandarach, and from the line of NAEVIUS, one of the most ancient Latin poets, "Merula sandaracino ore:" so that this colour must have been a bright yellow similar to that of the beak of the blackbird.* DIOSCORIDES describes the best σανδαράχη as approaching in colour to vermilion,† and the Greeks probably always applied this term to minium; but the Romans seem to have used it in a different sense; and some confusion was natural when different colours were prepared from the same substance by different degrees of calcination.

I have not detected the use of orpiment in any of the ancient fresco paintings; but a deep yellow approaching to orange, which covered a piece of stucco in the ruins near the monument of CAIUS CESTIUS, proved to be oxide of lead, and consisted of massicot mixed with minium. It is probable, that the ancients used many colours from lead of different tints between the usta of PLINY, which was our minium, and imperfectly decomposed ceruse, or pale massicot.

The yellows in the Aldobrandini picture are all ochres. I examined the colours in a very spirited picture, on the wall of one of the houses at Pompeii, of a lion and a man, they all proved to be red and yellow ochres.

IV. *Of the blue colours of the Ancients.*

Different shades of blue are used in the different apartments of the baths of Titus, and several very fine blues exist in the mixtures of colours to which I have referred in the last two sections.

These blues are pale or darker, according as they contain

* Histoire de la Peinture ancienne, page 199. † Lib. v. 122.

larger or smaller quantities of carbonate of lime, but when this carbonate of lime is dissolved by acids, they present the same body colour, a very fine blue powder similar to the best smalt or to ultramarine, rough to the touch, and which does not lose its colour by being heated to redness; but which becomes agglutinated and semifused at a white heat.

This blue I found was very little acted on by acids. Nitro-muriatic acid by being long boiled upon it gained, however, a slight tint of yellow, and afforded proofs of the presence of oxide of copper.

A quantity of the colour was fused for half an hour with twice its weight of hydrate of potassa; the mass which was bluish green was treated by muriatic acid in the manner usually employed for the analysis of siliceous stones, when it afforded a quantity of silica equal to more than $\frac{1}{3}$ of its weight. The colouring matter readily dissolved in solution of ammonia, to which it gave a bright blue tint, and it proved to be oxide of copper. The residuum afforded a considerable quantity of alumine, and a small quantity of lime.

Amongst some rubbish that had been collected in one of the chambers of the baths of Titus, I found several large lumps of a deep blue frit, which when powdered and mixed with chalk produced colours exactly the same as those used in the baths, and which when submitted to chemical tests were found to be the same in composition.

The minute quantity of lime found in this substance was not sufficient to account for its fusibility: it was therefore reasonable to expect the presence of a fixed alkali in it; and on fusing some of it with three times its weight of boracic acid, and treating the mass with nitric acid and carbonate of am-

monia, and afterwards distilling sulphuric acid from it, I procured from it sulphate of soda, which proves that it was a frit made by means of soda, and coloured with oxide of copper.

The undiluted colour in its form of frit is used for ornamenting some of the mouldings detached from the ceilings of the chambers in the baths of Titus: and the walls of one chamber between the compartments of red marble, bear proofs of having been covered with this frit, and retain a considerable quantity of it.

There is every reason to believe, that this is the colour described by Theophrastus as discovered by an Egyptian king;* and of which the manufactory is said to have been anciently established at Alexandria.

Vitruvius speaks of it, under the name of cæruleum,† as the colour used commonly in painting chambers, and states, that it was made in his time at Puzzuoli, where the method of fabricating it was brought from Egypt by Vestorius; he gives the method of preparing it by heating strongly together sand, flos nitri,‡ and filings of copper.

Pliny mentions other blues, which he calls species of sand (arenæ) from the mines of Egypt, Scythia, and Cyprus. These natural blues, there is reason to believe, were different preparations of lapis lazuli, and of the blue carbonates and arseniates of copper.

Both Pliny and Vitruvius speak of the Indian blue, which the first author states to be combustible, and which was evidently a species of indigo.

I have examined several blues in the fragments of fresco

* De Lapidibus, sect. xxviii. † Lib. vii. Cap. 11.

‡ This identifies the nitrum of the ancients with carbonate of soda.

painting from the ruins near the monument of CAIUS CESTIUS. In a deep blue approaching in tint to indigo, I found a little carbonate of copper, but the basis of this colour was the frit before described.

The blues in the Nozze Aldobrandine, from their resisting the action of acids, and from the effects of fire, I am inclined to consider as composed of the Alexandrian or Puzzuoli blue.

In an excavation made at Pompeii, in May 1814, at which I was present, a small pot containing a pale blue colour was dug up, which the exalted personage, by whose command the excavation was made, was so good as to put into my hands. It proved to be a mixture of carbonate of lime with the Alexandrian frit.*

VITRUVIUS states, that the ancients had a mode of imitating the Indian blue or indigo, by mixing the powder of the glass called by the Greeks ὕαλος, with selinusian "creta" or annularian "creta", which was white clay or chalk mixed with stained glass; the same practice is likewise referred to by PLINY.

There is much reason for supposing that this stained glass, or ὕαλος, was tinged with oxide of cobalt; and that these colours were similar to our smalt. I have not found any powdered colour of this kind in the baths of Titus, or in any other Roman ruins; but a blue glass tinged with cobalt is very common in those ruins, which when powdered forms a pale smalt.

I have examined many pastes and glasses that contain oxide of copper; they are all bluish green, green, or of an opaque watery blue. The transparent blue glass vessels which are

* This probably is the same colour as that examined by M. CHAPTAL. He did not search in it for alkali, or there is every reason to suppose he would have found soda.

found with the vases in the tombs in Magna Græcia are tinged with cobalt, and on analyzing different ancient transparent blue glasses which Mr. MILLINGEN was so good as to give me, I found cobalt in all of them.*

THEOPHRASTUS, in speaking of the manufacture of glass, states as a report that "χαλκὸς" was used to give it a fine colour, and it is extremely probable, that the Greeks took cobalt for a species of χαλκὸς. I have examined some Egyptian pastes which are all tinged blue and green with copper, but though I have made experiments on nine different specimens of ancient Greek and Roman *transparent* blue glass, I have not found copper in any, but cobalt in all of them.†

V. *Of the ancient greens.*

The ceiling of the chambers called the Baths of Livia is highly ornamented with gilding and paintings; the larger paintings have been removed, but the ground work and the borders remain. A fragment detached from the borders, which appears of the same colour as the ground work, was of a deep sea green. The colouring matter examined, proved to be soluble in acids with effervescence, and when precipitated from acids, it redissolved in solution of ammonia, giving it the

* The mere fusion of these glasses with alkali and digestion of the product with muriatic acid was sufficient to produce a sympathetic ink from them; even the silica separated by the acid gained a faint blue green tint by heat, and the solution in muriatic acid became parmanently green by the action of sulphuric acid, a phenomenon Dr. MARCET has observed as belonging to the muriate of cobalt.

† A gentleman at Milan informed me last summer that he had found oxide of cobalt in the blue glass found in the ruins of Hadrian's villa, and at this time I had no idea that cobalt was known to the ancients. Mr. HATCHETT, and Mr. KLAPROTH had both found oxide of copper in some ancient blue glasses, which I conceive must have been opaque.

bright blue tint produced by oxide of copper. There are several different shades of green employed in the baths of Titus, and on the fragments found near the monument of CAIUS CESTIUS: in the vase of mixed colours I found three different varieties; one, which approached to olive, was the common green earth of Verona; another, which was pale grass green, had the character of carbonate of copper mixed with chalk; and a third, which was sea green, was a green combination of copper mixed with the blue copper frit.

All the greens that I examined on the walls of the baths of Titus were combinations of copper. From the extreme brilliancy of a green which I found in the vineyard to which I have so often referred, I suspected that it might contain arsenious acid, and be analogous to SCHEELE's green; but on submitting it to experiments, it afforded no indications of this substance, and proved to be a pure carbonate of copper.

The greens of copper were well known to the Greeks; the most esteemed is described by THEOPHRASTUS and DIOSCORIDES under the name of χρυσοκόλλα, and is stated by both to be found in metallic veins.

VITRUVIUS mentions chrysocolla as a native substance found in copper mines, and PLINY speaks of an artificial chrysocolla made from the clay found in the neighbourhood of metallic veins, which clay was most probably impregnated with copper. He describes it as rendered green by the herb luteum. There is every reason to believe, that the native chrysocolla was carbonate of copper, and that the artificial was clay impregnated with sulphate of copper rendered green by a yellow die.

Some commentators have supposed that chrysocolla is the

same substance as borax, because PLINY has mentioned that a preparation called by this name was used by goldsmiths for soldering gold;* but nothing can be more gross than this mistake, which, however, has been copied into many elementary books of chemistry. The material used for soldering gold consisted of carbonate or oxide of copper mixed with alkaline phosphates. This is evident from the description of DIOSCORIDES "Περὶ τοῦ συκώλιμος Lib. v. c. 98, who says it was prepared from urine treated in brass mortars. PLINY says likewise, that it was prepared from "Cypria ærugine et pueri impubis urina, addito nitro."† The name of chrysocolla was probably derived from the green powder used by the goldsmiths, and which contained carbonate of copper as one of its ingredients.‡

Amongst the substances found in the baths of Titus were some masses of a grass green colour. I at first thought these might be specimens of native chrysocolla; they proved indeed to be carbonate of copper, but it had formed round longitudinal nuclei of red oxide of copper, so that probably these substances had been copper nails or small pieces of copper used in the building, converted by the action of the air, during so many centuries, into oxide and carbonate.

The ancients, as it appears from THEOPHRASTUS, were well

* Hist. de la Peinture ancienne, pag. 38. "Nos droguistes la nomme Borax."

† Lib. xxxiii. Cap. 5.

‡ The commentators have been likewise misled by PLINY's description, "chrysocolla humor est in puteis per venam auri defluens, &c." Ibid; but this is merely an inaccurate account of the decomposition of a vein containing copper. We have no reason for supposing that the Greeks and Romans were acquainted with borax. PLINY, probably misled by the application of the same name to different substances, considered chrysocolla as the cement of gold in mineral veins.

acquainted with verdigrise. VITRUVIUS mentions it amongst pigments, and probably many of the ancient greens, which are now carbonate of copper, were originally laid on in the state of acetite.

The ancients had beautiful deep green glasses, which I find are tinged with oxide of copper; but it does not appear that they used these glasses in a state of powder as pigments.

The greens of the Aldobrandini picture are all of copper, as was evident from the action of the muriatic acid upon them.

VI. *Of the purple of the Ancients.*

The Πορφύρα of the Greeks, and the ostrum of the Romans, was regarded as their most beautiful colour, and was prepared from shell fish.

VITRUVIUS* says, that the colour differed according to the country from which the shell fish was brought; that it afforded a colour deeper and more approaching to violet from the northern countries, and a redder colour from the southern coasts. He states, that it was prepared by beating the fish with instruments of iron, freeing the purple liquor from the shell containing it, and mixing it with a little honey: and PLINY says, that for the use of the painters argentine "creta"† was dyed with it: and both VITRUVIUS and PLINY say, that it was adulterated, or imitations of it made, by tinging "creta" with madder,‡ and "hysginum." The finest purple, PLINY

* Lib. vii. Cap. 13.

† Probably a clay used for polishing silver. The ancients were not acquainted with the distinction between aluminous and calcareous earths, and *creta* was a term applied to every white fine earthy powder.

‡ Madder was extensively used by the ancients in dying, and from this passage it is probable, that they were acquainted with the art of making a lake from it similar

says, had a tint like that of a deep coloured rose: and in painting, he states that it was laid on to give the last lustre to the sandyx, a composition made by calcining together red ochre and sandarach, and which therefore must have been nearly the same as our crimson.

In the baths of Titus there is a broken vase of earthen ware, which contains a pale rose colour; where it has been exposed to air, it has lost its tint, and is become of a cream colour, but the interior has a lustre approaching to that of carmine.

I have made many experiments on this colour. It is destroyed and becomes of a red brown by the action of concentrated acids and alkalies; but diluted acids dissolve a considerable quantity of carbonate of lime with which the body colour is mixed, and leave a substance of a bright rose colour: this substance when heated first blackens, and when urged with a strong flame becomes white; and treated with alkali, proves to be composed of siliceous, aluminous, and calcareous earths, with no sensible quantity of any metallic substance, except oxide of iron.

I endeavoured to discover if the colouring matter was combustible. It was gradually heated in a glass tube filled with oxygene; it did not inflame but became red hot sooner than it would have done had it been merely earthy matter: on exposing the gas in the tube to lime water, there was a precipitation of carbonate of lime. Some of it was mixed with hyperoxymuriate of potassa, and heated in a small retort;

to that used by modern painters. It was probably one of the colours used by the Egyptians in dying their stuffs of different colours from the same liquor, by means of mordants. If we can trust PLINY's account, they practised calico printing in a manner similar to the moderns. Lib. xxxv. Cap. 12.

when the salt fused there was a slight scintillation, a little moisture appeared, and the gas given off received into lime water occasioned a very evident precipitation.

It appeared from these experiments, that the colouring matter was a compound of either vegetable or animal origin. I threw some of it upon a hot iron, it emitted scarcely any smoke, and gave a smell which had some resemblance to that of prussic acid, but which was extremely faint.

When hydrate of potassa was fused in contact with it, the vapours that rose had no distinct ammoniacal smell; they gave indeed slight fumes to paper moistened with muriatic acid, but this is far from being an unequivocal proof of animal matter. I compared this colour with vegetable lake from madder, and animal lake from cochineal diluted to the same degree as nearly as could be judged, and fixed upon clays. The lake of madder, after being dissolved in strong muriatic acid, had its colour restored by alkalies, which was not the case with the ancient lake. The lake of madder likewise gave a much deeper tint to muriatic acid, and produced a tawny hue when its weak muriatic solution was acted on by muriate of iron; whereas the ancient lake did not change in colour. The ancient lake agreed with the lake of cochineal in being rendered of a deeper hue by weak alkalies, and of a brighter hue by weak acids; but it differed from it in being much more easily destroyed by strong acids. It agreed with both the vegetable and animal lakes in being immediately destroyed by a solution of chlorine.

The lake made from cochineal produced much denser fumes when exposed to fused potash, and afforded a distinct ammoniacal smell. The two modern lakes when burnt in oxygene

did not give stronger signs of inflammation than the ancient. I ascertained the loss of weight this ancient lake suffered by combustion, and found it only $\frac{1}{30}$, and this loss must in great part have depended on the expulsion of water from the clay on which it was fixed. This circumstance induced me to renounce the idea of attempting to determine its nature from the products of its decomposition; which in the case of so small a quantity of matter diffused over so large a quantity of surface could not have afforded unequivocal results.

The durability of this lake, whether vegetable or animal, is a very curious circumstance; but the exterior part which has been exposed to air has suffered.—This durability probably depends in a great measure upon the attractive powers of so large a mass of alumina; for whenever one proportion of a substance is combined with many proportions of another substance, it is very difficult to decompose or detach the one proportion.

From the circumstances which have been noticed respecting this colour, it is impossible to form an opinion whether it is of vegetable or animal origin. If of animal origin, it is most probably the Tyrian or marine purple: and by some comparative experiments on the purple obtained from shell fish the question might perhaps be decided.* It is very probable that the most expensive colour would be employed for orna-

* M. Chaptal considers the lake he found amongst the colours from Pompeii (as I have already mentioned) as of vegetable origin; and he founds his opinion upon the circumstance of its not affording by decomposition the smell peculiar to animal substances: but probably this smell, even if produced by recent purple colouring matter of animal origin, would not belong to colouring matter of 1700 years old. For it is most probably owing merely to albumen or gelatine not essential to the colouring particles, and much more rapidly decomposed.

menting the imperial baths; and it is not impossible that PLINY may have alluded to the palace of the Cæsars when he says "nunc et purpuris in parietes migrantibus, et India conferente fluminum suorum limum, et draconum et elephantorum saniem, nulla nobilis pictura est." Lib. xxxv. Cap. 32.

I have seen no colour of the same tint as this ancient lake in any of the ancient paintings in fresco. The purplish reds in the baths of Titus are mixtures of red ochres and the blues of copper.—In the Aldobrandini picture there is a purple in the garment of the Pronuba, but of an inferior hue; and this purple appears to be a compound mineral colour of the nature of these.—It was not destroyed by solution of chlorine; and when a little of it was exposed to muriatic acid, it rendered the acid yellow, and the remainder yielded a residual blue powder.

VII. *Of the blacks and browns of the Ancients.*

There is one chamber in the baths of Titus of which the ground work is black. I have found several fragments of stucco painted black both in the baths of Titus and in the vineyard above mentioned, and also in some ruins near the Porta del Popolo.—I scraped off some of these colours and submitted them to experiments: they were not acted on by acids or alkalies, they deflagrated with nitre, and had all the properties of pure carbonaceous matter.

I found no blacks, but three different shades of brown in the vase of mixed colours; one was snuff colour, one deep red brown, and the third a dark olive brown. The two first proved to be ochres which had been probably partially calcined; the third contained oxide of manganese, as well as

oxide of iron, and afforded chlorine when acted on by muriatic acid.

All the ancient authors describe the artificial Greek and Roman blacks as carbonaceous, and made either from the powder of charcoal or the decomposition of resin, (a species of lamp black) or from the lees of wine, or from the common soot of wood fires. PLINY mentions the inks of the cuttle fish, but says, "ex his non fit."* Some years ago I examined this substance, and found it a carbonaceous body mixed with gelatine. PLINY speaks of ivory black as invented by Apelles; he says likewise that there is a natural fossil black, and another black prepared from an earth of the colour of sulphur. Probably both these substances are ores of iron and manganese.

That the ancients were acquainted with the ores of manganese is evident from the use made of it in colouring glass. I have examined two specimens of ancient Roman purple glass, both of which were tinged with oxide of manganese.—PLINY speaks of different brown ochres, and particularly of one from Africa, which he names Cicerculum, which probably contained manganese: and THEOPHRASTUS mentions a fossil† which inflamed when oil was poured upon it, a property belonging to no other fossil substance now known but the *black wad*, an ore of manganese, and which is now found in Derbyshire.

The browns in the paintings in the baths of Livia, and in the Aldobrandini picture, are all produced by mixtures of ochres

* i. e. the atramentum.

† THEOPHRASTUS says it is like decomposed wood παρόμοιος ὢν ξύλῳ σαπρῷ, 13th page of John de Laet's edition.

with blacks. Those in the Aldobrandini picture yield oxide of iron to muriatic acid, but the darker shades were not touched by that acid, nor by solution of alkalies.

VIII. *Of the whites of the Ancients.*

The white colours in the Aldobrandini picture are soluble in acids with effervescence, and have the characters of carbonate of lime.

The principal white in the vase of mixed colours appears to be a very fine chalk. There is another white with a tint of cream colour, which is a fine aluminous clay.

The whites that I have examined from the baths of Titus, and those from other ruins, are all of the same kind.

I have not met with ceruse amongst the ancient colours, though we know from THEOPHRASTUS, VITRUVIUS, and PLINY, that it was a common colour: and VITRUVIUS describes it as made by the action of lead upon vinegar.

Several white clays are mentioned by PLINY as employed in painting, of which the Parætonium was considered as affording the finest colour.

IX. *Of the manner in which the Ancients applied their colours.*

It appears from VITRUVIUS that the colours used in fresco painting were applied moist to the surface of a stucco* formed of powdered marble cemented by lime; he states that the wall or ceiling had three distinct coatings of stucco made of this material, of which the first contained coarse powder of marble, the second the finer powder, and the third the finest

* Lib. vii. Cap. 2, 3, and 4.

powder of all, and that after this the wall was polished before the colour was applied. The stuccos that remain in the ruins of the baths of Titus and Livia are of this kind, and so is the ground of the Aldobrandini picture; they are beautifully white, and almost as hard as marble, and the granular marble of different degrees of fineness may be distinguished in them. This circumstance indeed offers a test of the antiquity of ruins at Rome. In the houses that have been built in the middle and later ages, decomposing lava has been mixed with the calcareous cement instead of granular marble, and the stuccos of these houses are grey or brown, and very coarse in their texture.

Pliny says that purple, orpiment, ceruse, the natural azure, indigo, and the meline white, were injured by application to wet stucco, which is easily explained in the case of orpiment, carbonate of copper, ceruse, and indigo, from their chemical composition.

Vitruvius states that in fresco painting vermilion changed if exposed to light, and he recommends the encaustic process for fixing the colour under this circumstance, namely, laying over it a coat of punic wax, and liquifying the wax so as to make a varnish for the colour.

Pliny describes this process as applied in painting ships; and we know from his authority that several pictures of the great Greek masters were painted in encaustic, and that the different colours were laid on mixed with wax. I have examined several pieces of the painted stuccos found in the different ruins, and likewise the Aldobrandini picture, with a view of ascertaining if any application had been made to fix the colour; but neither by the test of alcohol, nor by heat,

nor by the action of water, could I detect the presence of any wax varnish, or animal or vegetable gluten.

The pot of colours to which I have already referred, found at Pompeii, was blackened by smoke, as if it had been recently on a fire of wood. I thought that this might be owing to some process for dissolving gluten or varnish in the preparation of the colour; but I could detect no substance of this kind mixed with the colouring matter.

PLINY states, that gluten (our glue)* was used in painting with blacks: and this specific mention of its application would induce the belief that it was not employed with other colours, which adhered without difficulty to, and were imbibed by, a surface so polished and well prepared as the Roman stucco; and the lightness of carbonaceous matter alone probably rendered this application necessary.

X. *Some general observations.*

It appears from the facts that have been stated, and the authorities quoted, that the Greek and Roman painters had almost all the same colours as those employed by the great Italian masters at the period of the revival of the arts in Italy. They had indeed the advantage over them in two colours, the Vestorian or Egyptian azure, and the Tyrian or marine purple.

The azure, of which the excellence is proved by its duration for seventeen hundred years, may be easily and cheaply made; I find that fifteen parts by weight of carbonate of soda, twenty parts of powdered opaque flints, and three parts of copper filings strongly heated together for two hours, gave a

* Lib. xxxv. Cap. 25. "Omne atramentum sole perficitur, librarium gummi tectorium glutino admixto."

substance of exactly the same tint, and of nearly the same degree of fusibility, and which, when powdered, produced a fine deep sky blue.

The azure, the red and yellow ochres, and the blacks are the colours that seem not to have changed at all, in the ancient fresco paintings. The vermilion is darker than recently made Dutch cinnabar, and the red lead is inferior in tint to that sold in the shops. The greens in general are dull.

The principle of the composition of the Alexandrian frit is perfect; namely, that of embodying the colour in a composition resembling stone, so as to prevent the escape of elastic matter from it, or the decomposing action of the elements; this is a species of artificial lapis lazuli, the colouring matter of which is naturally inherent in a hard siliceous stone.

It is probable that other coloured frits may be made, and it is worth trying whether the beautiful purple given by oxide of gold, cannot be made useful in painting in a densely tinted glass.

Where frits cannot be employed, metallic combinations which are insoluble in water, and which are saturated with oxygene or some acid matter, it is evident from the proof of a duration of seventeen centuries, are the best pigments. In the red ochres the oxide of iron is fully combined with oxygene, and in the yellow ochres it is combined with oxygene and carbonic acid; and these colours have not changed. The carbonates of copper which contain an oxide and an acid have changed very little.

Massicot and orpiment were probably the least permanent amongst the ancient mineral colours.

Of the colours, the discovery of which is owing to the im-

provements in modern chemistry, the patent yellow is much more durable than any ancient yellow of the same brilliancy; and chromate of lead, an insoluble compound of a metallic acid with a metallic oxide, is a much more beautiful yellow than any possessed by the ancients, and, there is every reason to believe, is quite unalterable.

SCHEELE'S green (the arsenite of copper), and the insoluble muriatic combination of copper, will probably be found more unalterable than the ancient greens; and the sulphate of baryta offers a white superior to any possessed by the Greeks and Romans.

I have tried the effect of light and air upon some of the colours formed by the new substance iodine. Its combination with mercury offers a good red, but it is, I think, less beautiful than vermilion, and it appears to change more by the action of light.

Its compound with lead gives a beautiful yellow, little inferior to the chromate of lead; and I possess some of this colour which has been exposed to light and air without alteration for several months.

In many of the figures and ornaments in the outer chambers of the baths of Titus, where only outlines or spots remain, or shades of ochre, it is probable that vegetable or animal colours, such as indigo and the different dyed clays, were used.*

PLINY speaks of the celebrated Greek painters as employing only four colours. "Quatuor coloribus solis immortalia illa opera fecere: ex albis Melino, ex silaceis Attico, ex rubris

* Some excellent pictures have suffered very much in modern times from the same cause; the lakes in the frescos of the Vatican have lost much of the brilliancy which they must have possessed originally. The blues in many pictures of Paul Veronese are become muddy.

Sinopide Pontica, ex nigris atramento, Apelles, Echion, Melanthius, Nicomachus, clarissimi pictores;"* but as far as Apelles and Nicomachus are concerned, this is a mistake: and it is not unlikely that PLINY was misled by an imperfect recollection of a passage in CICERO, who describes the earlier Greek school as using only four colours; but the later Greek painters as perfect masters in all the resources of colouring. "Similis in pictura ratio est: in qua Zeuxim, et Polygnotum, et Timantem, et eorum, qui non sunt usi plus quam quatuor coloribus, formas et lineamenta laudamus: at in Actione, Nicomacho, Protogene, Apelle, jam perfecta sunt omnia." CICERO, Brutus, seu de claris oratoribus, c. 18. PLINY himself describes with enthusiasm the Venus ἀναδυομένη of Apelles: and in this picture the sea was represented, which required azure.

The great Greek painters, like the most illustrious artists of the Roman and Venetian school, were probably, however, sparing in the use of the more florid tints in historical and moral painting, and produced their effects rather by the contrasts of colouring in those parts of the picture where a deep and uniform tint might be used, than by brilliant drapery.

If red and yellow ochres, blacks and whites, were the colours most employed by Protogenes and Apelles, so they are likewise the colours most employed by RAPHAEL and TITIAN in their best style. The St. John and the Venus, in the tribune of the Gallery at Florence, offer striking examples of pictures in which all the deeper tints are evidently produced by red and yellow ochres, and carbonaceous substances.

As far as colours are concerned, these works are prepared for that immortality which they deserve; but unfortunately

* Lib. xxxv. c. 32.

the oil and the canvas are vegetable materials, and liable to decomposition, and the last is less durable than even the wood on which the Greek artists painted their celebrated pictures.

It is unfortunate that the materials for receiving those works which are worthy of passing down to posterity as eternal monuments of genius, taste, and industry, are not imperishable marble* or stone: and that frits, or unalterable metallic combinations, have not been the only pigments employed by great artists; and that their varnishes have not been sought for amongst the transparent combinations of the earths with water, or amongst the crystalline transparent compounds unalterable in the atmosphere.†

* Copper, it is evident, from the specimens in the ruins of Pompeii, is a very perishable material, and, therefore, even enamels made on copper will yield to time. Canvas, by being impregnated with bitumen, is rendered much more durable, as is evident from the duration of the linen impregnated with bitumen and asphaltum used for infolding the Egyptian mummies.

† The artificial hydrat of alumina will probably be found to be a substance of this kind: possibly the solution of boracic acid in alcohol will form a varnish.—The solution of sulphur in alcohol is likewise worthy of an experiment. Many other similar combinations might be named.

Rome, January 14th, 1815.

IX. *On the laws which regulate the polarisation of light by reflexion from transparent bodies.* *By* David Brewster, *LL. D. F. R. S. Edin. and F. S. A. Edin. In a letter addressed to the Right Hon. Sir* Joseph Banks, *Bart. K. B. P. R. S.*

Read March 16, 1815.

Dear Sir,

The discovery of the polarisation of light by reflexion, constitutes a memorable epoch in the history of optics; and the name of Malus, who first made known this remarkable property of bodies, will be for ever associated with a branch of science which he had the sole merit of creating. By a few brilliant and comprehensive experiments he established the general fact, that light acquired the same property as one of the pencils formed by double refraction, when it was reflected at a particular angle from the surfaces of all transparent bodies: he found that the angle of incidence at which this property was communicated, was greater in bodies of a high refractive power, and he measured, with considerable accuracy, the polarising angles for glass and water. In order to discover the law which regulated the phenomena, he compared these angles with the refractive and dispersive powers of glass and water, and finding that there was no relation between these properties of transparent bodies, he draws the following general conclusion. "The polarising angle neither "follows the order of the refractive powers, nor that of the

"dispersive forces. It is a property of bodies independent "of the other modes of action which they exercise upon "light."

This premature generalisation of a few imperfectly ascertained facts, is perhaps equalled only by the mistake of Sir ISAAC NEWTON, who pronounced the construction of an achromatic telescope to be incompatible with the known principles of optics. Like NEWTON, too, MALUS himself abandoned the enquiry; and even his learned associates in the Institute, to whom he bequeathed the prosecution of his views, have sought for fame in the investigation of other properties of polarised light.

In the summer of 1811, when my attention was first turned to this subject, I repeated the experiments of MALUS, and measured the polarising angles of a great number of transparent bodies. I endeavoured, in vain, to connect these results by some general principle: the measures for *water* and the *precious stones* afforded a surprising coincidence between the indices of refraction and the tangents of the polarising angles; but the results for glass formed an exception, and resisted every method of classification. Disappointed in my expectations, I abandoned the enquiry for more than twelve months, but having occasion to measure the polarising angle of *topaz*, I was astonished at its coincidence with the preceding law, and again attempted to reduce the results obtained from *glass* under the same principle. The piece which I used had two surfaces excellently polished. The polarising angle of one of these surfaces almost exactly accorded with the law of the tangents, but with the other surface there was a deviation of no less than two degrees. Upon examining the cause of this

anomalous result, I found that one of the surfaces had suffered some chemical change, and reflected less light than any other part of the glass. This artificial substance acquires an incrustation, or experiences a decomposition by exposure to the air, which alters its polarising angle without altering its general refractive power. The perplexing anomalies which Bouguer observed in the reflective power of plate glass, were owing to the same cause, and so liable is this substance to these changes, that by the aid of heat alone, I have produced a variation of 9° on the polarising angle of flint glass, and given it the power of acting upon light like the coloured oxides of steel.

Having thus ascertained the cause of the anomalies presented by glass, I compared the various angles which I had measured, and found that they were all represented by the following simple law.

The index of refraction is the tangent of the angle of polarisation.

In the course of last summer, when I had the pleasure of seeing M. Arago, I mentioned to him the relation which I had discovered between the refractive powers, and the tangents of the polarising angles. He informed me, that he had found the polarising angle of air to be 45° or 47°, which being at the very extremity of the scale would afford a good test of the accuracy of the law. Now, if we take the refractive power of air at 1.0029 the polarising angle will be 45° 0′ 32″, a result which agrees most strikingly with the observed angle.

In the following table I have given the polarising angles of eighteen transparent bodies, as determined by experiment, and as deduced from the law of the tangents. I have added in

the *fourth* column the differences between the calculated and observed angles, and in the *fifth* column the calculated angles of polarisation for the second surfaces of the bodies subjected to experiment.

Table containing the calculated and observed polarising angles for various bodies.

Names of the Bodies.	Calculated polarising angles for the *first* surface.	Observed polarising angles for the *first* surface.	Difference between the calculated and observed angles.	Calculated polarising angles for the *second* surface.
	° ′ ″	°		° ′ ″
Air	45 0 32	45 or 47		44 59 28
Water	53 11 0	53° 45′	0° 26′ —	36° 49′
Fluor spar	55 9 0	54 50	0 19 —	34 51
Obsidian	56 6 0	56 3	0 3 —	33 54
Birdlime	56 40 0	56 46	0 6 +	33 20
Sulphate of lime	56 45 0	56 28	0 17 —	33 15
Rock crystal	56 58 0	57 22	0 24 +	33 2
Opal coloured glass	58 33 0	58 1	0 32 —	31 27
Topaz	58 34 0	58 40	0 6 +	31 26
Mother of pearl	58 50 0	58 47	0 3 —	31 10
Iceland spar	58 51 0	58 23	0 28 —	31 9
Orange coloured glass	59 28 0	59 12	0 16 —	30 32
Spinelle ruby	60 25 0	60 16	0 9 —	29 35
Zircon	63 0 0	63 8	0 8 +	27 0
Glass of antimony	64 30 0	64 45	0 15 +	25 30
Sulphur	63 45 0	64 10	0 25 +	26 15
Diamond	68 1 0	68 2	0 1 +	21 59
Chromate of Lead	68 3 0	67 42	0 21 —	21 56

The coincidence between the calculated and observed angles, as shown in the preceding Table, must appear very remarkable to those who are aware of the difficulty of measuring

correctly the index of refraction for the *mean* refrangible ray, and the still greater difficulty of determining the angle at which the intensity of the evanescent pencil is a minimum. The total amount of the errors in seventeen observations is 259 minutes, which gives an average error of 15′ for each observation. In general the observed angles are less than the calculated angles, the number of negative being to the number of positive differences as 174′ is to 85′.

This circumstance arises from two separate causes, which ought to be carefully kept in view in all experiments on the polarising angles of bodies.

1. In order to illustrate the first of these causes, let us take the case of *Zircon*, in which the intensity of the evanescent pencil is a minimum at 63° of incidence. At 64° the intensity of the pencil which vanishes at 63° is much greater than that of the pencil at 62° on account of its falling more obliquely upon the reflecting surface, and consequently the intensity of that pencil varies more rapidly in passing from 64° to 63° than from 62° to 63°. Hence, in determining the point of minimum intensity, it is more likely, from the way in which the observation must be made, that the observed angle will fall *below* than above the real polarising angle.

2. As the differently coloured rays have different angles of polarisation, and as the most luminous rays of the spectrum have less refractive power than the mean refrangible rays, the observed polarising ought always to be less than the polarising angle for the mean rays. Hence, all the observed angles in the preceding Table ought to be increased by a certain quantity, or, what is the same thing, the index of refraction for the most luminous rays ought to be employed instead

of the mean index of refraction in computing the first column.

The law of the polarisation of light by reflexion being thus experimentally established, we shall now proceed to point out its geometrical consequences, and to arrange, under separate propositions, the new truths to which it leads, as well as those which I have obtained from direct experiment. It will thus be seen, that the subject assumes a scientific form, and that we can calculate *a priori*, the result of every experiment, whether the light is incident upon the first or second surface of transparent bodies, or upon the separating surface of different media, or whether it undergoes a series of successive reflexions in the same plane, or in planes at right angles to each other.

SECT. I. *On the laws of the polarisation of light, by reflexion from the first surfaces of transparent bodies.*

PROP. I.

When a pencil of light is incident upon a transparent body at an angle, whose tangent is equal to the index of refraction, the reflected portion will be either wholly polarised, or the quantity of polarised light which it contains will be a maximum.

This proposition is a repetition of the general law already established. In *water*, *glass*, and other bodies, whose refractive power is less than 1.6, almost the whole of the pencil is polarised, at the polarising angle; but in diamond, realgar, chromate of lead, oil of cassia, &c. whose refractive power exceeds 1.6, the whole of the reflected pencil does not suffer polarisation, but the quantity of polarised light is a *maximum* at the angle indicated in the proposition. See Sect. V.

PROP. II.

The differently coloured rays which compose a beam of white light are polarised at angles of reflexion whose tangents are equal to their respective indices of refraction.

This Proposition might have been admitted as a corollary to Prop. I.; but I have established it by the following experiment. A ray of light incident upon *oil of cassia* at an angle of 58° 38′, suffers its maximum polarisation. When the angle is 57° 38′ the *blue* rays predominate in the pencil that approaches to evanescence, while at an angle of 59° 38′ the *red* rays predominate. Hence it follows, that the polarisation of the red light is a maximum at an angle below the mean polarising angle, and the polarisation of the blue light a maximum at an angle, above the mean polarising angle. See Sect. V.

PROP. III.

When the refractive power of any body is infinitely small, its polarising angle will be 45°.

The limit to which the index of refraction constantly approaches is 1.000 which is the tangent of 45°

PROP. IV.

When a pencil of light is polarised by reflexion, the sum of the angles of incidence and refraction is a right angle.

Let MN, (Fig. 1, Pl. VI.) be the reflecting surface, and BA, a ray of light polarised by reflexion in the direction AD, and let AC be the refracted ray. Then since EF, the tangent of the polarising angle BAE, is equal to m, or the index of refraction, we have by the law of the sines, $CL = \frac{BG}{m} = \frac{BG}{EF}$. But from the

similar triangles ABH, AEF, we have AH or BG : HB :: EF : Rad.; and $HB = \frac{BG}{EF}$, consequently CL = HB and the angle BAN = CAK. But EAB + BAN = 90°, hence EAB + CAK = 90°.

Cor. The complement of the polarising angle is equal to the angle of refraction.

PROP. V.

When a ray of light is polarised by reflexion, the reflected ray forms a right angle with the refracted ray.

Since the angles DAM, BAN, CAK (Fig. 1.) are equal to one another, the angle DAC is equal to the right angle MAK: hence the reflected ray AD forms a right angle with the refracted ray AC.

PROP. VI.

If light were polarised simply by the action of the reflecting force, the polarising angle would be 45°.

For when the refracting force is infinitely small, the polarising angle is 45°. The reflecting force is also infinitely small in this case, but any diminution of the reflecting force, however great, does not alter the direction of the reflected ray with respect to the incident ray, or the position of any point or side of a ray with regard to the direction of its motion. It may also be remarked that 45° is the only angle of reflexion at which any point or side of a ray makes a revolution of 90° relative to the direction of its motion. See Prop. VIII, and Cor. 2, of the same Proposition.

PROP. VII.

Every ray of light polarised by reflexion has been acted upon by the refracting force before it has suffered reflexion.

This follows from the light not being polarised at 45°, but at various angles increasing with the refracting force.

Cor. It results from this Proposition, that light suffers a partial refraction before it is reflected; and that the refractive force extends to a greater distance than the reflecting force from the surface of transparent bodies. This result is not only consistent with the most extensive analogies, but affords an explanation of phenomena, which have hitherto been unexplained.

BOUGUER, for example, observed that at $87\frac{1}{2}°$ of incidence, a surface of water reflected 614 rays, while glass reflected only 584. Now supposing the light to be refracted by the water and the glass, before it suffers reflexion, the real angle of incidence upon the glass will be only 57° 44′, while the angle of incidence upon the water will be 61° 5′; so that the pencil being incident more obliquely upon the water, ought to be more copiously reflected.

PROP. VIII.

When a ray of light is incident at the polarising angle upon any substance whatever, it receives such a change in its direction, by the action of the refracting force, that the real angle of incidence at which it is reflected and polarised is 45°

Let MN, Fig. 2, be the refracting and the reflecting surface, and OP the termination of the sphere of refracting activity. Let a ray RG be incident at G, at the polarising angle, and

let it be refracted into the line GB, before it is reflected from the surface MN.* A part of the ray GB will penetrate the surface MN, and be refracted into the line BF, while another part will be reflected in the direction BA, and again refracted at A into the line AS. Continue SA to C and FB to D. Then since half of the refraction is supposed to be performed before the ray reaches B, and half of it after it penetrates the medium MN, we have BAC = DBC = half the angle of deviation. But by Prop. V, ADB is a right angle, hence ABC is also a right angle, and the angles ABE, GBE, each half a right angle, or 45°.

Cor. 1. At the instant of reflexion, when the refraction at B commences, the refracted ray sets off at right angles to the reflected portion.

Cor. 2. The *real angle of polarisation* is 45°, the effect of the refractive force being merely to bend the ray of light so as to make it suffer reflexion at this particular angle.

Cor. 3. The excess of the angle formed by the incident and the polarised ray, above a right angle, is equal to the angle of deviation. The angle PAB, Fig. 1, which is equal to the angle of deviation OAC, is obviously the excess of DAB above the right angle DAP.

Sect. II. *On the laws of the polarisation of light by reflexion from the second surfaces of transparent bodies.*

When a ray of light is incident upon a parallel plate of

* In order to keep the figure from being complicated, I have supposed the reflexion to take place all at once when the ray reaches the surface MN. The demonstration would have been exactly the same if the ray had been represented as suffering a gradual reflexion in passing through the sphere of reflecting activity.

any transparent body, the image reflected by the first surface is nearly coincident with the image reflected by the second surface, and MALUS observed that they were both polarised at the same time. As the angles at which the rays are incident upon the two surfaces are very different, this result appeared quite inexplicable; but it will be seen from the following Propositions, that the simultaneous polarisation of the two pencils is a necessary consequence of the general law, and derives from that law the most satisfactory explanation.

PROP. IX.

When a pencil of light is incident on the second surface of transparent bodies, at an angle whose co-tangent is equal to the index of refraction, the reflected portion will be either wholly polarised, or the quantity of polarised light which it contains will be a maximum.

As the images formed by the first and second surfaces of a transparent plate are simultaneously polarised, this Proposition is established by the experimental results in the preceding Table.

PROP. X.

The angle of polarisation at the second surface of transparent bodies, is the complement of the angle of polarisation at the first surface.

As the angle of incidence at the second surface is equal to the angle of refraction at the first surface, and as this latter angle is, by the Corollary to Prop. IV. equal to the complement of the angle of polarisation, it follows, that the two polarising angles are complementary to each other.

PROP. XI.

When a ray of light is polarised by reflexion from the second surface of transparent bodies, the reflected ray will form a right angle with the refracted ray.

Let AB, Fig. 3, be a ray incident at the first surface MN, AD the ray polarised at that surface, AC the ray incident at the second surface PQ, and CM the ray polarised at that surface; then if CF be the refracted ray, the angle MCF is a right angle. By Prop. V, DAC is a right angle, and on account of the parallelism of MN, PC, and BA, CF, the angle FCP is equal to DAM, but MCP is equal to MAC, hence the whole MCF is equal to the whole DAC, or a right angle.

Cor. 1. The ray CM, reflected by the second surface, is at right angles to the ray AB incident on the first surface.

Cor. 2. The internal reflected ray CM forms with the external reflected ray AD, an angle equal to the angle of deviation CAO.

Cor. 3. The ray CF emerging from the second surface forms with the first reflected ray, AD an angle equal to the complement of the angle of deviation.

PROP. XII.

When a ray of light is incident at the polarising angle, upon the second surface of transparent bodies, it receives such a change in its direction from the action of the refracting force, that the real angle of incidence, at which it is reflected and polarised, is 45°.

By the very same reasoning which was used in Prop. XI,

it may be shown that the angle ABC, *fig.* 4, is a right angle; but BC being a continuation of BG, ABG will also be a right angle, and consequently the angle of incidence EBG will be half a right angle, or 45°.

PROP. XIII.

When a ray of light is incident on the second surface of a transparent body at an angle whose sine is greater than the reciprocal of the index of refraction, or at an angle greater than the angle of total reflexion, the reflected light will consist of two pencils, one of which is polarised in the plane of reflexion, and the other in a plane perpendicular to the plane of reflexion.

The experiments by which I ascertained this singular property were conducted in a manner similar to those of MALUS upon polished metals. A ray of light moving horizontally in the direction of the meridian, after having been polarised in the plane of the horizon, was made to fall upon the second surface of a transparent body facing the south-east or south-west, and inclined at such an angle to the horizon, as to receive the ray near the limit of total reflexion. The polarised ray was depolarised by the action of the second surface, so that the images of the object from which it proceeded, when viewed through a prism of calcareous spar, continued visible in every part of its revolution, an effect which could only be produced by the power of the second surface to form two oppositely polarised images.

When the plane of the second reflexion is either parallel, or perpendicular to the plane in which the ray was originally polarised, the ray will suffer no change by the second reflexion, one of the images formed by a prism of calcareous spar vanishing in every quadrant of its circular motion.

In order to ascertain the relation between the polarising angle at the second surface of transparent bodies, and the angle at which they reflect the whole of the incident pencil, let us make.

The index of refraction	$= m$
Sine of the angle of total reflexion	$\frac{1}{m}$
Cotangent of the polarising angle	m
Tangent of the polarising angle	$\frac{1}{m}$

Since the sine of any angle is always less than the tangent, the polarising angle whose tangent is $\frac{1}{m}$ will always be less than the angle of total reflexion whose sine is $\frac{1}{m}$. The angle of polarisation, therefore, must fall without the limit of total reflexion, but it will gradually approach to that limit as the refractive power increases. When the pencil, however, is incident within the sphere of total reflexion, the quantity of polarised light is so near its maximum, that the experiments can be conducted with almost the same result, as if the polarising angle had exceeded the angle of total reflexion. The only consequence of the difference between the two angles is, that the depolarised image is inferior in point of intensity to the other image.

The following measures for *flint glass* with a refractive power of 1.600, and of *diamond* with a refractive power of 2.80, will show the relations between these two angles.

	°	′
Polarising angle for the second surface of *flint glass*	32	0
Angle at which total reflexion commences	38	45
Difference	6°	45′

	°	′
Polarising angle for the second surface of *diamond*	21	59
Angle at which total reflexion commences -	23	46
Difference	1°	47′

SECT. III. *On the laws of the polarisation of light by reflexion from the separating surfaces of different media.*

Although the attention of MALUS was directed to this branch of the subject, yet he does not appear to have obtained even a single measure of the angles at which light is polarised at the separating surfaces of different media. "After having de-"termined," he observes," the angles under which polarisa-"tion takes place with respect to different bodies, *water* and "*glass*, for example, I sought for that at which the same "phenomenon would take place at their surface of separation, "when they are in contact, but the law according to which "this last angle depends upon the first two still remains to "be discovered." I have often attempted the same experiment with the same want of success, but besides being unable to determine the *law*, I could never find that there was any maximum angle of polarisation at the common surface of water and glass, when the light was incident from air. It is curious to remark, that MALUS does not say, that such an angle existed although this may be considered as implied in the observation that the law still remains to be determined. Now it is sufficiently singular, as will appear from the following propositions, that there is no angle of incidence at the first surface of the water which will admit the light to be polarised at the common surface of the water and the glass.

PROP. XIV.

When a pencil of light is incident upon the separating surface of two media having different indices of refraction m m', it will be polarised at an angle whose tangent is equal to the quotient of the greater index of refraction divided by the lesser, or $\frac{m}{m'}$.

This Proposition is a necessary consequence of the general law, and is also deduced from direct experiment.

If we call A the angle whose tangent is equal to $\frac{m}{m'}$, then the corresponding angle at which the pencil is incident from air upon the first surface of the upper medium, or $\alpha = \sin. A \times m$.

In the case of *water* and *glass*, where m is equal to 1.525, and m' to 1.336, we have the polarising angle at the surface of separation, or $A = 48° 47'$, and $\sin. A \times m' = 1.0048$, consequently α is greater than 90°. Hence it follows, that when a ray of light is incident upon a parallel plate of water lying upon a plate of glass, there is no angle of incidence upon the first surface of the water at which the ray will suffer polarisation at the separating surface of the two media. The polarisation of the incident pencil increases from 0° to 90°, and is nearly complete at 90°.

When m is equal to 1.508, which is sometimes the case, then $\sin. A \times m' = 1.000$, and $\alpha = 90°$ exactly.

This conclusion was so unexpected that I immediately endeavoured to confirm it by experiment. The result was exactly conformable to the law: the polarisation of the pencil became more and more perfect from 0° to 90° of incidence. Between 80° and 90° the change was scarcely perceptible, owing to the slow variation of the sines, for when the pencil is

incident at 80°, the angle of incidence at the separating surface is 47° 29′, while at an incidence of 90° it is no more than 48° 28′, differing only 59′ from the other.

Prop. xv.

When light is polarised at the separating surface of two media, the sum of the angles of incidence and refraction is a right angle, and the reflected ray forms a right angle with the refracted ray.

This proposition is demonstrated in the same manner as Prop. IV and V, the separating surface producing always the same phenomena as the first surface of any body, whose index of refraction is equal to the quotient of the indices of refraction for the two contiguous bodies.

It would be a waste of time to extend the application of the general law to other cases where the reflecting surfaces are inclined at different angles, or where the incident pencil traverses a number of different media, and receives particular changes at each successive reflexion. We shall, therefore, go on to another branch of enquiry, and consider the laws which regulate the phenomena when a pencil is polarised by several successive reflexions, a subject to which Malus has not even alluded.

SECT. IV. *On the law of the polarisation of light by successive reflexions.*

PROP. XVI.

When a ray of light is incident at any angle except a right angle upon the surface of a transparent body, a certain portion of the reflected light is completely polarised, while the remaining portion has suffered a physical change, or has acquired, in various degrees, a character approaching to complete polarisation.

This proposition has been established by direct experiments made with glass, whose polarising angle is 56° 45′.

If a pencil of light is reflected from glass at an angle of 62° 30′, or 50° 20′, i. e. either above or below the polarising angle, the portion of light which is not completely polarised, has so far received this character, that it will be completely polarised by a second reflexion at the same angle, whereas had it been absolutely unpolarised light, it could not have been polarised at any angle different from 56° 45′, the real angle of polarisation.

In like manner *three* reflexions at an angle of 65° 38′ or 46° 30′, or *four* reflections at an angle of 67° 38′, or 48° 51′ will polarise the whole pencil, while at angles above 82° or below 18° more than 100 reflexions are necessary to produce complete polarisation.

The truth of the proposition for the transmitted rays is established by the experiments which I have already published on the polarisation of light by oblique refraction.* If a pencil

* See *Phil. Trans.* 1814, Part I. p. 219.

of light is polarised by twenty-four plates at an angle of 60°, then it is obvious that twelve plates will not polarise the whole pencil at the same angle.

Let us suppose that the portion not polarised amounts to twenty rays out of a hundred. Then, if these twenty rays were absolutely unpolarised, and in the same state as direct light, they would require to pass through twenty-four plates at an angle of 60°, in order to be polarised: but the experiments show that they require only to pass through other twelve plates at that angle. It therefore follows, that the twenty rays have been half polarised by the first twelve plates, and the polarisation completed by the other twelve. Hence we see the mistake of MALUS, who observes, that the light transmitted obliquely through glass consists 1st. of a quantity of polarised light, and "2d. *of another portion not modified,* "*and which preserves the characters of direct light.*"

PROP. XVII.

If a ray of light is partly polarised by reflexion at any angle, it will be more and more polarised by every successive reflexion in the same plane, till its polarisation is complete, whether the reflexions are made at angles all above or all below the polarising angle, or at angles some of which are above and some below the polarising angle.

This proposition is deduced from numerous experiments which may be easily repeated. It is extremely difficult, however, on account of the rapid attenuation of the light when it has undergone a few reflexions from glass, to determine satisfactorily the relation between the number of reflexions and the angles of incidence at which they polarise a pencil of light. The experiments which I have made are represented by the

following law, A, a being the angles of incidence above and below the polarising angle, m the index of refraction, and N, n the number of reflexions above or below the polarising angle.

$$\text{Tang. } A = m \times \sqrt[3]{N}$$

when the angle of incidence is *greater* than the polarising angle for one reflexion, and

$$\text{Tang. } a = \frac{m}{\sqrt[3]{n}}$$

when the angle of incidence is less than the polarising angle for one reflexion. Hence we have

$$N = \left(\frac{\text{tang. } A}{m}\right)^3 \text{ and}$$

$$n = \left(\frac{m}{\text{tang. } a}\right)^3$$

When the successive reflections are made at different angles A, A′, A″ above the polarising angle, or a, a', a'' below the polarising angle, the pencil will be just polarised when

$$\left(\frac{1}{\frac{\text{tang. } A}{m}}\right)^3 + \left(\frac{1}{\frac{\text{tang. } A'}{m}}\right)^3 + \left(\frac{1}{\frac{\text{tang. } A''}{m}}\right)^3 = 1. \text{ or when}$$

$$\left(\frac{1}{\frac{m}{\text{tang. } a}}\right)^3 + \left(\frac{1}{\frac{m}{\text{tang. } a'}}\right)^3 + \left(\frac{1}{\frac{m}{\text{tang. } a''}}\right)^3 = 1.$$

When some of the reflexions are made above, and some below the polarising angle, at the angles A, a, a' A″ for example, then the pencil will be polarised when

$$\left(\frac{1}{\frac{\text{tang. } A}{m}}\right)^3 + \left(\frac{1}{\frac{m}{\text{tang. } a}}\right)^3 + \left(\frac{1}{\frac{m}{\text{tang. } a'}}\right)^3 + \left(\frac{1}{\frac{\text{tang. } A''}{m}}\right)^3 = 1.$$

When the refractive power is infinitely small, which is nearly the case in *air*, and the *gases*, we have $m = 1.000$ and $N = (\text{tang. } A)^3$, $n = \left(\frac{1}{\text{tang. } a}\right)^3$. Hence when $N = n$, cotang. a = tang. A, and therefore a will in this case be the complement

of A, the same effect being produced at angles equidistant from the maximum polarising angle.

In order to apply the formulæ with facility in ascertaining the number of reflexions necessary to polarise a pencil of light, I have calculated the following Table containing values of A and *a* for various values of N and *n*, the reflexions being supposed to be made from glass, whose index of refraction is equal to 1.525.

Table showing the angles at which a pencil of light is polarised by any number of reflexions at the same angle.

When the angles are *greater* than the maximum polarising angle, or 56° 45′.		When the angles are *less* than the maximum polarising angle, or 56° 45′.	
Number of reflexions necessary to polarise the incident light.	Angles at which the incident light is wholly polarised by the number of reflexions in Col. 1.	Number of reflexions necessary to polarise the incident light.	Angles at which the incident light is wholly polarised by the number of reflexions in Col. 3.
	° ′		° ′
1	56 45	1	56 45
2	62 30	2	50 26
3	65 33	3	46 30
4	67 33	4	43 51
5	69 1	5	41 48
6	70 9	6	40 0
7	71 5	7	38 33
8	71 51	8	37 20
9	72 30	9	36 15
10	73 4	10	35 18
27	77 40	27	26 39
64	80 41	64	20 32
100	81 57	100	18 11
125	82 32	125	16 58
1000	86 15	1000	8 46

Let it be required, for example, to ascertain what effect will be produced upon a ray of light by four reflexions at the following angles.

	°	′
Above the polarising angle -	77	40
	70	9
Below the polarising angle - -	50	26
	35	18

The values of N and n in the Table corresponding to these angles are, 27, 6, 2, 10, and 64, and therefore we have

$$\frac{1}{2} + \frac{1}{6} + \frac{1}{2} + \frac{1}{10} = \frac{2604}{3240},$$

which being less than 1, the ray will not be polarised, but will require another reflexion either at 69° 1′ or 41° 43′, for the values of N and n corresponding to these angles are both 5 and $\frac{1}{5} + \frac{2604}{3240} = \frac{1626}{1620} = 1$ very nearly.

The formulæ in the preceding proposition are equally applicable to the second surfaces of transparent bodies, and to the separating surfaces of different media, $\frac{1}{m}$, and $\frac{m}{m'}$ being in these cases substituted in place of m.

PROP. XVIII.

When a ray of light is once completely polarised, its polarisation will suffer no change, and the ray will preserve all its optical properties after any number of reflexions at any angle in the plane in which it was polarised, or after any number of refractions in a plane at right angles to that in which it was polarised.

If a ray is polarised by reflexion in the plane of the horizon, and is afterwards reflected at various angles in the plane of the horizon, one of the images will always vanish in the same position of the prism, as if it had not suffered a second

reflection. The same thing will happen if the direct ray is transmitted through a bundle of glass plates in which the plane of refraction is perpendicular to the horizon.

Prop. xix.

When a polarised ray is incident at any angle upon a transparent body, in a plane at right angles to the plane of its primitive polarisation, a portion of the ray will lose its property of being reflected, and will entirely penetrate the transparent body. This portion of light, which has lost its reflexibility, increases as the angle of incidence approaches to the polarising angle, when it becomes a maximum.

A part of this Proposition constitutes one of the beautiful discoveries of Malus, who found that at the polarising angle the second plate of glass "would no longer reflect a single "particle of light, either from its first or second surface."

The rest of the Proposition I have established by various experiments. In realgar, diamond, and oil of cassia, and in substances whose refractive power exceeds 1.600, the portion of light which *suffers reflexion* at the polarising angle is very considerable, and it will be seen from the Propositions in Sect. V., that if strong lights are used, there are no circumstances under which *every particle* of a beam of white light can lose its reflexibility.

PROP. XX.

If the reflecting plane upon which the polarised ray is received, is made to deviate in the slightest degree from the position which deprives the maximum portion of the ray of its reflexibility, a part of the light that had formerly lost its reflexibility will now suffer reflexion, and will be polarised in the plane of the SECOND REFLEXION, *whereas before the deviation took place, this portion of light was polarised in the plane of the first reflexion.*

When the plane of the second reflexion is perpendicular to the plane of primitive polarisation, every particle of the ray that suffers reflexion will be polarised in the last of these planes, but when the least deviation takes place, a part of the polarised ray is depolarised, so that it receives its character from the second reflexion, and is polarised in the plane of that reflexion. It is very interesting to observe two such opposite effects produced by the most minute change in the position of the second reflecting plane.

PROP. XXI.

If a ray of light reflected from a transparent body at any angle, excepting the polarising angle, is reflected from another body in a plane at right angles to that of its first reflexion, the reflected portion will be polarised by the second reflexion in the same manner, and at the same angle as if it had been direct light.

This proposition is deduced from experiment. The portion of light that is polarised at the first reflexion, will lose its reflexibility at the second reflexion, in proportion as the angle of reflexion approaches to the polarising angle.

PROP. XXII.

When a ray of light polarised by reflexion, is incident at any angle on the surface of a transparent body, so that the plane of the second reflexion is at right angles to the plane of the first reflexion, and suffers successive reflexions in the plane of the second reflexion, it will lose its reflexibility when it has undergone that number of reflexions which would have been necessary to polarise it, had it been direct light.

This result was at first deduced a priori from Prop. XVII. and XIX., and was afterwards established by experiment. The number of reflexions may be determined by the formulæ in Prop. XVII.

PROP. XXIII.

When a beam of light is emitted by the sun, or by any other body which does not shine by reflected light, the particles which compose it are in every state of POSITIVE *and* NEGATIVE *polarisation from particles completely polarised to particles not polarised at all.*

This Proposition is an expression of the experimental results in Prop. XVI. and XVII., and may be illustrated in the following manner, the terms *positive* and *negative* polarisation being employed to denote the two kinds of polarisation by reflexion and refraction at the polarising angle, or by reflexion in two opposite planes. A ray of direct light, before it is incident upon glass, may therefore be represented as consisting of a number of particles p, p, &c. of the following character.

$$+\frac{p}{0^\circ}, \frac{p}{1^\circ}, \frac{p}{2^\circ}, \frac{p}{3^\circ}, \frac{p}{4^\circ}, \frac{p}{5^\circ}, \frac{p}{6^\circ} \cdots\cdots \frac{p}{50^\circ\,45'}$$

$$-\frac{p}{0^\circ}, \frac{p}{1^\circ}, \frac{p}{2^\circ}, \frac{p}{3^\circ}, \frac{p}{4^\circ}, \frac{p}{5^\circ}, \frac{p}{6^\circ} \cdots\cdots \frac{p}{50^\circ\,45'}$$

The particle $+\frac{p}{0^\circ}$ will represent a particle so completely polarised in a positive manner, that it will be polarised by reflexion at 0° of incidence; $-\frac{p}{0^\circ}$ will represent a particle so completely polarised in a negative manner that it will be polarised by reflexion in an opposite plane at 0° of incidence; $+\frac{p}{1^\circ}$ a particle so far polarised that it will require only a reflexion at 1° of incidence to complete its polarisation, and so on with all the other particles till we come to $\frac{p}{56^\circ 45'}$, which is a particle of direct light so completely unpolarised that it requires to be reflected at the maximum polarising angle before it can suffer complete polarisation.

This peculiar state of the rays before they fall upon a transparent body might have been deduced *a priori* by considering that when a mass of particles is projected from a self-luminous body, the different sides of the rays, or poles of the luminous particles must have every possible position relative to the direction of their motion, which is the state described in the Proposition. If we break a tourmaline, for example, into a number of fragments, there will be a positive and a negative electrical pole in every possible direction, and a mass of moving tourmalines will have, nearly, the same relation to the tourmaline itself in which all the axes are regularly arranged, as a beam of direct has to a beam of polarised light.

Corollary 1. A beam of light that has suffered reflexion at any angle above 0°, will be in a state which may be represented in the following manner, the angle of incidence being supposed to be 4°.

Direct light $+\frac{p}{0^\circ}, \frac{p}{1^\circ}, \frac{p}{2^\circ}, \frac{p}{3^\circ}, \frac{p}{4^\circ}, \frac{p}{5^\circ}, \frac{p}{6^\circ} \cdots \frac{p}{56^\circ 45'}$

Light reflected at an angle of 4° $+\frac{p}{0^\circ}, \frac{p}{0^\circ}, \frac{p}{0^\circ}, \frac{p}{0^\circ}, \frac{p}{0^\circ}, \frac{p}{x5^\circ}, \frac{p}{x6^\circ} \cdots \frac{p}{x(56^\circ 45')}$.

The negative part of the reflected beam may be represented in a similar manner. The particle of direct light $\frac{p}{0^\circ}$ being already polarised, will suffer no change by the reflexion (Prop. XVIII.) The particle $\frac{p}{1^\circ}$ being susceptible of polarisation by reflexion at an angle of 1° will also be polarised at any angle above 1°, and will therefore come into the state of $\frac{p}{0^\circ}$. In like manner the particles $\frac{p}{2^\circ}$, $\frac{p}{3^\circ}$, $\frac{p}{4^\circ}$ will all be polarised, and assume the state represented by $\frac{p}{0^\circ}$. The particle $\frac{p}{5^\circ}$ being susceptible of polarisation only at an angle of 5° or more will not be polarised at 4°, but will be brought into a state very near that of polarised light. It will therefore be represented by $\frac{p}{x5^\circ}$, x being a fractional coefficient, always less than 1, to be determined by the formulæ in Prop. XVII. For the same reason all the other particles will be brought into a state nearer that of perfect polarisation, and will be represented by $\frac{p}{x6^\circ}$ and $\frac{p}{x(56^\circ 45')}$.

Cor. 2. In general, all the particles of a direct beam of light whose denominator is equal to or less than the angle of incidence will be brought by reflexion into the state of $\frac{p}{0^\circ}$, while all the particles whose denominator exceeds the angle of incidence will be brought into a state which may be found by multiplying their state in the direct beam by $\frac{1}{x}$, x being determined by Prop. XVII.

SECT. V. *On the nature and origin of the apparently unpolarised light which exists at the maximum polarising angle.*

I have already shown in a former paper,* that in substances of a high refractive power, such as *realgar* and *diamond*, there is a great quantity of apparently unpolarised light reflected at the polarising angle, so that the image which would have vanished by the application of calcareous spar, had the reflexion been made from *water* or *crown glass*, possessed in these cases a considerable brilliancy. The comparative intensity of the light of this image is indeed so great, that only a very small portion of the incident light seems to be polarised. I was at first much surprised at witnessing this phenomenon, as I had been led to believe from the first Memoir of MALUS, that one of the pencils formed by calcareous spar vanished when the light was reflected from all other bodies as well as from *water* and *glass*. There is some reason to think, however, that MALUS afterwards observed the same fact, for in a subsequent Memoir, he makes use of the term *maximum polarising angle*, in which the knowledge of it seems to be implied.

The extreme difficulty of accounting for such an unexpected phenomenon, probably deterred him from even mentioning the subject in any of his Memoirs; and I am not ashamed to avow that the investigation of this point alone has cost me more labour than any other branch of the polarisation of light. The existence of a quantity of apparently unpolarised light, in a pencil reflected at the polarising angle, appeared completely paradoxical, and it was obvious that no satisfactory generalisation of the phenomena could be given while this difficulty remained unsolved.

* See Phil. Trans. for 1814, Part I. p. 230.

I at first imagined that bodies with a high refractive power approached to the metals in their mode of action upon light, but this conjecture was refuted by experiments which showed that the pencil did not consist of two oppositely polarised portions. When I discovered the law of successive reflexions, as stated in Prop. XVI. and XVII., the difficulty of explaining the phenomenon seemed to increase. What MALUS would have called the unpolarised portion of a beam of light, reflected at 62° from glass, was now shown to be so far polarised, that its polarisation was completed by a second reflexion at the same angle, so that it became still more improbable that unpolarised light could exist at the polarising angle itself. All these difficulties, however, were immediately removed by the discovery of the law of the tangents, and of the polarisation of the differently coloured rays at angles of incidence depending on their respective indices of refraction. The explanation which now suggested itself was confirmed by experiment, and I was thus led after much fruitless investigation to the results expressed in the following Propositions.

PROP. XXIV.

If a pencil of white light is incident at the maximum polarising angle upon any transparent body whatever, a portion of the reflected pencil, consisting of the mean refrangible rays, will be completely polarised, while another portion of the beam, consisting of the blue and red rays, will not be completely polarised, and will therefore not vanish when the image from which the light proceeds is examined with a prism of calcareous spar.

It is obvious from Prop. II. that all the rays which compose a beam of white light cannot be polarised at the same angle

of incidence. When the pencil is incident at the maximum polarising angle, or at an angle whose tangent is equal to the index of refraction for the mean refrangible rays, these rays alone will be polarised. Neither the *red* rays, which are incident at an angle above their polarising angle, nor the blue rays which are incident at an angle below their polarising angle, will be completely polarised; and when the reflected pencil which contains them is viewed through a doubly refracting crystal, the *mean* refrangible rays will vanish, while the *red* and *blue* rays will compose a beam nearly white, and will not vanish, in consequence of its not being completely polarised.

PROP. XXV.

If a pencil of WHITE *light polarised by reflexion is incident at the polarising angle upon any transparent surface, so that the plane of the second reflexion is at right angles to the plane of its primitive polarisation, a portion of the pencil consisting of the mean refrangible rays will lose its reflexibility, and will entirely penetrate the second surface, while another portion of the beam, composed of the blue and red rays, will not lose its reflexibility, but will suffer reflexion and refraction like ordinary light.*

This proposition founded also on experiment may be proved by the same reasoning as the preceding, for since the angle at which polarised rays lose their reflexibility is the same as the angle at which they are polarised, only one set of the rays which compose a white beam can lose their reflexibility at the same angle.

Prop. xxvi.

The imperfectly polarised portion of light described in Prop. XXIV. and the portion which does not lose its reflexibility as described in Prop. XXV., increase with the dispersive and the refractive power of the reflecting surface, so that in substances where the dispersive and refractive forces are very great, these portions constitute in the one case almost the whole of the reflected pencil, and in the other almost the whole of the pencil that would have been reflected under ordinary circumstances.

When the dispersive power of the reflecting surface is so high as to throw the blue and red rays to a great distance from the mean ray, the quantity of polarised light at the mean polarising angle must be very small, and must obviously diminish as the dispersive power increases, the quantity of imperfectly polarised light consisting of the blue and red rays increasing in the same proportion. When the refractive power is high, the polarising angle increases, and the quantity of reflected light becomes very great, being, in the case of diamond, about one half of the incident beam. Hence in rock crystal, which has a higher refractive power, and a lower dispersive power than water, the image does not wholly vanish at the polarising angle.

PROP. XXVII.

If a pencil of HOMOGENEOUS *or coloured light is incident upon any transparent body at an angle whose tangent is equal to the index of its refraction, every ray of the reflected pencil will be completely polarised in the plane of reflexion.*

This proposition is a necessary consequence of those which precede it; and I have also established it by direct experiments upon diamond and realgar.

PROP. XXVIII.

If a pencil of HOMOGENEOUS *or coloured light is incident under the circumstances described in Prop. XXV., every ray of it will lose its reflexibility.*

This proposition, which is also deducible from those which precede it, has been established by experiment.

PROP. XXIX.

If a beam of WHITE *light suffers more than one reflexion, every ray of it will be completely polarised when the angles of incidence are of such a magnitude that the sum of the terms of the formulæ given under Prop. XVII. is equal to* 1, *the index of refraction for the extreme red ray being substituted in place of* m *if the angles are above the polarising angle, and the index of refraction for the extreme blue ray if the angles are below the polarising angle.*

This Proposition is manifestly deducible from Prop. XVII. compared with Prop. XXVII. Calling *dm* the part of the

whole refraction to which the dispersion, or the distance between the extreme rays is equal, the formulæ will become

$$\left(\frac{1}{\frac{\text{tang. A.}}{m-\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. A'}}{m-\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. A''}}{m-\frac{1}{2}dm}}\right)^3=1$$

$$\left(\frac{1}{\frac{\text{tang. }a}{m+\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. }a'}{m+\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. }a''}{m+\frac{1}{2}dm}}\right)^3=1$$

If the angles are partly above, and partly below the polarising angle, for example, at the angles A, a, a' A'' then the formula will become

$$\left(\frac{1}{\frac{\text{tang. A}}{m-\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. }a}{m+\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. }a'}{m+\frac{1}{2}dm}}\right)^3+\left(\frac{1}{\frac{\text{tang. A''}}{m-\frac{1}{2}dm}}\right)^3=1$$

Scholium.

I have determined the values of dm for 151 different substances, and have published a Table containing 137 of these in my *Treatise on New Philosophical Instruments*, p. 315. The value of m or the mean index of refraction, was found in the common way by measuring the angle of deviation produced by a prism of the substance under examination. The values of dm were computed, from measures taken with a new instrument, by means of a formula investigated by Boscovich, and used in the reduction of all his valuable experiments. This formula requires that the ray should be incident perpendicularly upon the first surface, but it will be found in practice that the dispersion of the prism under examination is equally corrected by the standard prism, when the ray is incident several degrees on either side of the perpendicular.

I have thus endeavoured as briefly as possible, and perhaps

more briefly than a new subject required, to give an account of the experiments and reasonings by which I have established the laws of the polarisation of light by reflexion from transparent bodies. These experiments have been extended to other branches of this subject, and in subsequent Memoirs I shall take the liberty of soliciting your attention to the laws which regulate the polarisation of light by *transmission through uncrystallized plates*;—by *reflexion from metallic and oxidated surfaces*; and by the *separation of light into two pencils by the action* of regularly crystallized bodies. In the investigation of the properties of metallic and oxidated surfaces, my experiments have been attended with the most successful results. I have discovered that the beautiful *complementary colours* produced by the action of crystalline bodies upon polarised light, are exhibited under singular circumstances by reflexions from *silver* and *gold*, and to a certain degree from *other metals*;—and that some metallic bodies have the power of polarising a beam of light in the plane of incidence by six or seven successive reflexions, while other metals are not able to polarise it even after twenty or thirty successive reflexions.

In these enquiries I have made use of no hypothetical assumptions. In imitation of MALUS, the language of theory has been occasionally employed, but the terms thus introduced are merely expressive of experimental results, and enable us to avoid frequent and perplexing circumlocutions. The science of physical optics is not yet in such a state as to authorise the construction of a new nomenclature. When discovery shall have accumulated a greater number of facts, and connected them together by general laws, we may then safely begin to impose better names, and to speculate respecting the

Fig. 1.

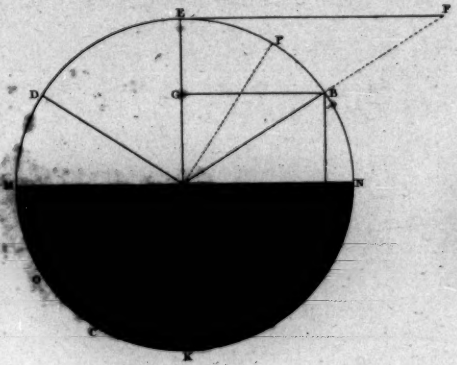


Fig. 3.

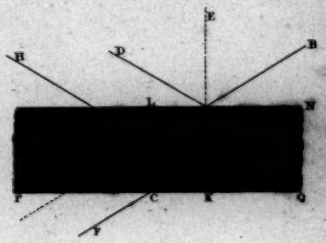


Fig. 2.

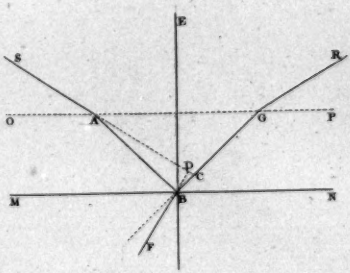
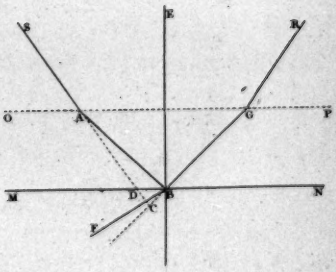


Fig. 4.



cause of those wonderful phenomena which light exhibits under all its various modifications.

In the preceding pages, I have more than once had occasion to establish conclusions opposite to those which MALUS had deduced from less numerous experiments; and indeed the whole of this paper is founded on relations which he believed to have no existence. In differing, however, from this eminent philosopher, I trust I have always done it with that respect which it is impossible not to feel for his character and labours. It has fallen to the lot of few to enrich science with so many new and striking discoveries, and if he has failed in pursuing them through all their consequences, we must ascribe it to the limited interval which he was allowed to devote to science, and to the influence of that cruel disease which terminated so prematurely his short but brilliant career. Those, who without repeating his experiments endeavoured during his life to depreciate his labours, are alone capable of wounding his memory. Those who, like him, have pursued science under the oppression of bodily suffering;—who have been instructed and delighted with his discoveries, and who have patiently followed him in the path of research, will feel it their truest pride to do justice to his memory, and will never be able to review his labours without mingling their sorrow with their admiration.

I have the honour to be, &c.

DAVID BREWSTER.

Edinburgh, February 11, 1815.

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METEOROLOGICAL JOURNAL,

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OF THE

ROYAL SOCIETY,

BY ORDER OF THE

PRESIDENT AND COUNCIL.

MDCCCXV.

METEOROLOGICAL JOURNAL

for January, 1814.

1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Rain this Month 1,152 Inches.	Winds. Points.	Winds. Str.	Weather.
Jan. 1	8	0	26	41	30,20	76		E	1	Thick fog.
	3	0	30	44	30,12	75		E	0	Thick fog.
2	8	0	28	40	29,89	77		E	0,1	Foggy.
	3	0	33	39	29,83	77		SW	1	Cloudy.
3	8	0	30	40	29,73	77		W	0	Foggy.
	3	0	31	40	29,67	78		W	1	Foggy.
4	8	0	30	40	29,42	77		N	1	Snow.
	3	0	29	42	29,30	74		NE	1	Cloudy.
5	8	0	31	39	29,18	77		N	1,2	Cloudy.
	3	0	33	43	29,13	80		E	2	Snow.
6	8	0	33	41	29,09	78		N	1	Cloudy.
	3	0	32	43	29,32	76		NE	1	Cloudy.
7	8	0	24	39	29,61	74		E	2	Cloudy.
	3	0	27	42	29,63	72		NNE	1	Fine.
8	8	0	22	37	29,63	74		N	1	Fine.
	3	0	30	41	29,63	77		N	1	Cloudy.
9	8	0	24	36	29,62	76		E	1	Cloudy.
	3	0	27	37	29,65	75		NE	1	Fine.
10	8	0	17	33	29,77	72		E	1	Foggy.
	3	0	26	38	29,82	72		E	1	Cloudy.
11	8	0	22	29	29,88	69		ESE	1,2	Cloudy.
	3	0	24	36	29,85	69		E	1	Cloudy.
12	8	0	21	33	29,54	69		N	1	Fine, rather hazy.
	3	0	26	38	29,48	68		NW	1	Cloudy.
13	8	0	25	34	29,90	73		N	1	Hazy.
	3	0	30	37	30,06	70		E	1,2	Fine.
14	8	0	22	33	30,01	68		E	1,2	Cloudy.
	3	0	24	37	29,87	68		E	2	Cloudy.
15	8	0	25	34	29,61	70		E	1	Cloudy.
	3	0	28	38	29,57	70		N	1	Cloudy.
16	8	0	27	35	29,39	75		NE	1	Cloudy.
	3	0	31	35	29,23	77		NE	1	Cloudy.

METEOROLOGICAL JOURNAL

for January, 1814.

1814	Time. H.	Time. M.	Therm. without.	Therm. within.	Barom.	Hygrometer.		Winds. Points.	Winds. Str.	Weather.
			°	°	Inches.	°				
Jan. 17	8	0	24	34	29,62	71		N	1	Fine.
	3	0	27	37	29,70	62		NE	1	Cloudy, [night.
18	8	0	31	35	29,12	79		E	1	Snow. Much snow in the
	3	0	32	40	29,10	79		E	1	Snow.
19	8	0	32	35	29,09	79		E	1	Cloudy.
	3	0	32	40	29,07	79		E	2	Snow.
20	8	0	29	37	29,37	75		N	2	Snow or sleet.
	3	0	31	40	29,58	70		N		Cloudy.
21	8	0	21	37	29,77	70		W	1	Snow.
	3	0	27	41	29,78	68		W	1	Fine.
22	8	0	22	36	29,75	70		NW	1	Cloudy.
	3	0	28	40	29,74	70		N	2	Fine.
23	8	0	24	35	29,84	72		N	1	Fine.
	3	0	31	37	29,75	71		NE	1	Cloudy.
24	8	0	26	35	29,78	72		N	1	Cloudy.
	3	0	28	39	29,81	72		N	1	Fine.
25	8	0	27	37	29,88	70		NW	1	Foggy.
	3	0	30	40	29,88	65		W	1	Cloudy.
26	8	0	32	37	29,64	73		SW	1	Snow.
	3	0	34	41	29,49	76		S	1	Cloudy.
27	8	0	33	38	29,23	79		S	1	Cloudy.
	3	0	37	38	29,17	75		S	1	Cloudy.
28	8	0	35	42	29,16	79		W	1	Cloudy.
	3	0	36	44	29,24	67		W	1	Cloudy.
29	8	0	33	42	28,66	78		SE	2	Cloudy.
	3	0	40	47	28,32	79		SW	2	Rain.
30	8	0	33	43	28,90	72		W	0,1	Hazy.
	3	0	38	42	29,11	69		W	1	Cloudy.
31	8	0	29	40	29,30	73		W	1	Fine.
	3	0	36	45	29,41	67		W	1	Cloudy.

Rain this Month 1,122 Inches.

METEOROLOGICAL JOURNAL

for February 1814.

1814	Time. H. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer.		Winds. Points.	Str.	Weather.
Feb. 1	8 0	32	41	29,83	67		W	1	Fine.
	3 0	37	47	30,00	64		SW	1	Fine.
2	8 0	35	42	29,93	75		N	1	Cloudy.
	3 0	38	47	29,98	70		N	1	Cloudy.
3	8 0	28	41	30,06	72		NW	1	Cloudy.
	3 0	33	46	30,01	68		N	1	Fine.
4	8 0	25	42	30,05	72		NE	1	Cloudy.
	3 0	33	47	30,12	66		E	1	Fine.
5	8 0	29	41	30,14	70		S	1	Cloudy.
	3 0	35	46	29,97	76		W	1	Rain.
6	8 0	39	43	29,72	78		W	1	Cloudy.
	3 0	42	44	29,57	72		NW	1	Fine.
7	8 0	36	42	29,62	70		W	1	Cloudy.
	3 0	41	46	29,68	67		W	1	Cloudy.
8	8 0	40	43	29,54	78		W	1	Rain.
	3 0	47	49	29,38	68		N	1	Fine.
9	8 0	38	46	29,67	71		W	1	Cloudy.
	3 0	46	50	29,82	69		NW	1	Cloudy.
10	8 0	47	48	29,99	78		SW	1	Rain.
	3 0	47	52	30,03	74		SW	1	Cloudy.
11	8 0	42	50	30,04	76		S	2	Cloudy.
	3 0	48	55	29,98	69		S	1	Cloudy.
12	8 0	42	51	29,99	73		S	1	Cloudy.
	3 0	47	52	30,00	75		S	1	Cloudy.
13	8 0	42	51	29,96	76		S	1	Cloudy.
	3 0	45	52	29,97	72		S	1	Cloudy.
14	8 0	38	50	29,93	75		E	1	Cloudy.
	3 0	38	52	30,01	68		E	1	Cloudy.
15	8 0	39	48	30,10	71		NE	1	Hazy.
	3 0	40	53	30,11	69		NE	1	Fine.
16	8 0	33	47	30,14	69		E	1	Cloudy.
	3 0	42	52	30,23	69		N	1	Fine.

Rain this Month 0,538 Inches.

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for February 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °		Winds. Points.	Str.	Weather.
Feb. 17	8	0	33	48	30,40	69		E	1	Cloudy.
	3	0	34	50	30,46	64		N	1	Fine.
18	8	0	24	44	30,42	70		W	1	Fine.
	3	0	40	50	30,32	67		W	1	Fine.
19	8	0	37	46	30,29	75		N	1	Rain.
	3	0	39	49	30,28	71		N	1	Cloudy.
20	8	0	27	44	30,44	69		N	1	Cloudy.
	3	0	38	48	30,43	64		N	1	Fine.
21	8	0	26	42	30,36	70		W	0,1	Cloudy.
	3	0	38	48	30,34	66		W	1	Cloudy.
22	8	0	28	43	30,30	70		SW	1	Thick fog.
	3	0	38	49	30,33	64		E	1	Cloudy.
23	8	0	27	42	30,27	68		E	1	Fine, rather hazy.
	3	0	31	49	30,23	61		E	1	Fine.
24	8	0	24	41	30,17	65		E	1	Fine.
	3	0	32	50	30,20	63		E	1	Fine.
25	8	0	23	42	30,22	66		E	1	Fine, rather hazy.
	3	0	32	50	30,19	62		E	1	Fine.
26	8	0	27	42	30,06	67		E	1	Cloudy.
	3	0	33	47	30,02	63		E	1	Fine.
27	8	0	27	41	30,11	72		N	1	Hazy.
	3	0	34	45	30,05	66		E by S	1	Cloudy.
28	8	0	32	41	29,87	71		SE	1	Thick and cloudy.
	3	0	40	45	29,68	73		SW	1	Cloudy.

Rain this Month 0,528 Inches.

METEOROLOGICAL JOURNAL

for March, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Str.	Weather.
Mar. 1	8	0	40	44	29,13	79	S by W	2	Cloudy.
	3	0	38	46	28,88	74	NW	1	Rain.
2	8	0	33	43	28,92	73	SW	1	Fine.
	3	0	37	48	28,80	74	SW	1	Cloudy.
3	8	0	34	44	28,85	76	E	1	Cloudy.
	3	0	40	48	28,95	68	S	1	Cloudy.
4	8	0	34	46	29,19	73	N	1	Cloudy.
	3	0	35	47	29,29	73	N	1	Cloudy.
5	8	0	33	44	29,55	74	N	1	Cloudy.
	3	0	34	45	29,69	79	N	1	Cloudy.
6	8	0	30	42	29,85	66	N	1	Cloudy.
	3	0	34	42	29,80	64	NE	1	Cloudy. [night.
7	8	0	31	40	29,69	73	SE	1	Snow. Much snow in the
	3	0	29	42	29,75	68	E	1	Cloudy.
8	8	0	29	40	29,81	73	N	1	Snow.
	3	0	31	44	29,82	66	E	1	Cloudy.
9	8	0	29	40	29,68	74	N	1	Fine.
	3	0	31	43	29,65	73	E	1	Rain.
10	8	0	30	40	29,58	72	E	1	Sleet.
	3	0	35	44	29,52	75	NE	1	Rain.
11	8	0	30	41	29,47	74	N	1	Cloudy.
	3	0	34	44	29,52	71	E	1	Cloudy.
12	8	0	30	41	29,70	73	N	1	Cloudy.
	3	0	35	44	29,75	73	N	1	Snow.
13	8	0	32	41	29,99	74	N	1	Cloudy.
	3	0	34	42	30,07	71	NE	1	Cloudy.
14	8	0	31	39	30,18	70	N	1	Cloudy.
	3	0	33	43	30,21	69	NNE	1	Cloudy.
15	8	0	30	40	30,33	70	E	1	Cloudy.
	3	0	34	43	30,36	67	W	1	Cloudy.
16	8	0	32	40	30,39	72	E	1	Cloudy.
	3	0	36	46	30,39	70	N	1	Cloudy.

Rain this Month 0,718 Inches.

METEOROLOGICAL JOURNAL
for March, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Str.	Weather.
Mar. 17	8	0	32	40	30,31	72	E	1	Cloudy.
	3	0	35	44	30,31	71	E	1	Cloudy.
18	8	0	29	42	30,27	75	N	1	Cloudy.
	3	0	32	45	30,19	73	NE	1	Cloudy.
19	8	0	29	42	30,05	74	SE	1	Cloudy.
	3	0	31	43	29,93	74	SE	1	Cloudy.
20	8	0	31	40	29,82	74	SSE	1	Cloudy.
	3	0	42	45	29,75	73	SSW	1	Fine.
21	7	30	40	43	29,69	75	E	1	Thick and cloudy.
	3	0	45	46	29,67	77	S	1	Rain.
22	7	30	44	46	29,62	80	SSE	1	Rain.
	3	0	48	49	29,68	68	S	1	Cloudy.
23	7	30	40	47	29,77	73	E	1	Hazy.
	3	0	50	51	29,80	63	SW	1	Cloudy.
24	7	30	38	48	29,80	73	S	1	Cloudy.
	3	0	45	52	29,67	74	S	1	Rain.
25	7	30	42	51	29,66	76	W	1	Cloudy.
	3	0	49	55	29,66	69	WSW	1	Cloudy.
26	7	30	39	51	29,65	73	S	1	Cloudy.
	3	0	50	53	29,66	64	SW	1	Cloudy.
27	7	30	43	51	29,87	73	W	1	Cloudy.
	3	0	52	54	29,91	66	W	1	Fine.
28	7	30	45	50	29,88	73	SSE	1	Fine.
	3	0	52	54	29,76	63	SE	1	Cloudy.
29	7	30	45	52	29,57	67	E	1	Cloudy.
	3	0	49	55	29,58	71	W	1	Cloudy.
30	7	30	41	52	29,78	73	S	1	Foggy.
	3	0	54	58	29,70	60	W	1	Fine.
31	7	30	46	52	29,96	71	S	1	Cloudy.
	3	0	49	56	29,88	73	S	2	Rain.

Rain this Month 0,718 Inches.

METEOROLOGICAL JOURNAL

for April, 1814.

1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer.		Winds. Points.	Winds. Str.	Weather.
Apr. 1	7	30	47	54	29.74	76	Rain this Month 1,241 Inches.	S	1	Cloudy.
	3	0	53	60	29.67	63		S	1	Fine.
2	7	30	46	54	29.41	77		S	2	Fine.
	3	0	51	57	29.38	66		SW	2	Cloudy.
3	7	30	46	53	29.40	71		SW	1	Fine.
	3	0	52	59	29.48	56		W	1	Fine.
4	7	30	43	53	29.61	70		NE	1	Cloudy.
	3	0	53	57	29.65	60		E	1	Cloudy.
5	7	30	44	53	29.74	70		NE	1	Fine.
	3	0	52	57	29.78	60		E	1	Cloudy.
6	7	30	46	54	29.96	75		W	1	Thick and hazy.
	3	0	54	59	30.00	62		W	1	Fine.
7	7	30	46	54	30.11	72		W	1	Cloudy.
	3	0	55	59	30.16	63		E	1	Fine.
8	7	30	46	54	30.25	73		E	1	Cloudy and hazy.
	3	0	53	62	30.28	57		E	1	Fine.
9	7	0	44	55	30.24	45		N	1	Fine.
	3	0	55	62	30.20	54		E	1	Fine.
10	7	0	46	55	30.13	46		E	1	Fine.
	3	0	56	62	30.09	54		SE	1	Fine.
11	7	0	46	55	30.04	71		E	1	Fine.
	3	0	57	62	30.00	59		E	1	Fine.
12	7	0	44	55	29.92	70		E	1	Cloudy.
	3	0	62	64	29.87	54		SW	1	Fair.
13	7	0	56	58	29.86	61		N	1	Hazy.
	3	0	64	64	29.81	65		E	1	Fine.
14	7	0	53	60	29.72	63		E	1	Fine, rather hazy.
	3	0	54	67	29.68	62		SW	1	Fair.
15	7	0	54	61	29.59	65		SE	1	Fine.
	3	0	57	63	29.45	65		W	2	Rain.
16	7	0	52	59	29.51	67		S	2	Cloudy.
	3	0	58	62	29.51	63		S	3	Cloudy.

METEOROLOGICAL JOURNAL

for April, 1814.

1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Winds. Str.	Weather.
Apr. 17	7	0	54	59	29,32	74	SE	2	Rain.
	3	0	58	62	29,47	60	SW	1,2	Fine.
18	7	0	50	57	29,66	68	S	1	Rain.
	3	0	59	62	29,57	65	W	1	Cloudy.
19	7	0	51	57	29,67	68	SE	1	Fine.
	3	0	57	63	29,69	59	S	1	Fine.
20	7	0	52	58	29,73	69	E	1	Cloudy.
	3	0	55	59	29,73	59	E	1	Cloudy.
21	7	0	51	58	29,73	70	W	1	Fine.
	3	0	55	60	29,71	60	W	1	Cloudy.
22	7	0	45	56	29,83	66	W	1	Cloudy.
	3	0	54	58	29,84	55	NW	1	Cloudy.
23	7	0	43	54	30,06	66	W	1	Cloudy.
	3	0	51	56	30,02	65	S	1	Rain.
24	7	0	45	54	29,83	67	NW	1	Cloudy.
	3	0	49	55	29,85	59	NE	1	Cloudy.
25	7	0	44	52	29,86	68	N	1	Cloudy.
	3	0	49	54	29,88	67	N	1	Cloudy.
26	7	0	44	51	29,91	69	N	1	Cloudy.
	3	0	50	56	29,99	63	N	1	Cloudy.
27	7	0	43	52	30,15	69	N	1	Fine.
	3	0	48	54	30,16	63	E	1	Cloudy.
28	7	0	44	52	30,17	67	SE	1	Cloudy.
	3	0	49	56	30,17	67	S	1,2	Rain.
29	7	0	45	54	30,11	70	SSE	1	Rain.
	3	0	53	55	30,07	62	S	1	Cloudy.
30	7	0	50	53	30,06	62	S	2	Cloudy.
	3	0	58	59	30,10	54	S	1,2	Cloudy.

Rain this Month 1,241 Inches.

METEOROLOGICAL JOURNAL

for May, 1814.

1814	Time. H.	Time. M.	Therm. without.	Therm. within.	Barom. Inches.	Hygrometer.		Winds. Points.	Winds. Str.	Weather.
						°				
May 1	7	0	51	54	30,19	57		S	1	Fair.
	3	0	60	61	30,20	54		SW	1	Fine.
2	7	0	54	56	30,20	59		W	1	Cloudy.
	3	0	57	58	30,19	69		E	1	Cloudy.
3	7	0	51	54	30,08	63		E	1	Fine.
	3	0	56	63	29,97	59		SE	1	Fair.
4	7	0	47	56	29,91	62		NE	1	Cloudy.
	3	0	50	58	29,82	58		E	1	Cloudy.
5	7	0	43	53	29,60	63		E	1	Cloudy.
	3	0	52	54	29,41	68		E	1	Rain.
6	7	0	48	54	29,43	77		SE	1	Cloudy.
	3	0	55	56	29,44	76		W	1	Rain.
7	7	0	48	55	29,76	76		E	1	Cloudy.
	3	0	59	57	29,88	63		W	1	Cloudy.
8	7	0	53	56	30,01	70		W	1	Cloudy.
	3	0	62	61	30,04	58		N	1	Cloudy.
9	7	0	50	55	30,19	59		E	1	Cloudy.
	3	0	52	57	30,23	60		E	1	Cloudy.
10	7	0	44	54	30,33	64		NE	1	Cloudy.
	3	0	52	59	30,36	56		NE	1	Cloudy.
11	7	0	44	53	30,46	62		E	1	Cloudy.
	3	0	52	59	30,43	56		E	1	Fair.
12	7	0	44	53	30,39	65		N	1	Cloudy.
	3	0	53	60	30,34	55		E	1	Cloudy.
13	7	0	48	56	30,18	70		NW	1	Cloudy.
	3	0	48	57	30,06	71		N	1	Cloudy.
14	7	0	45	55	30,02	72		N	1	Cloudy.
	3	0	50	56	30,03	65		N	1	Cloudy.
15	7	0	47	54	30,03	67		N	1	Cloudy.
	3	0	53	57	29,98	61		N	1	Cloudy.
16	7	0	44	54	29,98	67		SE	1	Cloudy.
	3	0	54	56	29,97	58		NE	1	Cloudy.

Rain this Month 1,779 Inches.

METEOROLOGICAL JOURNAL
for May, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer.		Winds. Points.	Str.	Weather.
May 17	7	0	47	55	30,12	71		E	1	Cloudy.
	3	0	58	62	30,14	55		E	1	Cloudy.
18	7	0	51	56	30,17	67		N	1	Cloudy.
	3	0	60	63	30,16	53		E	1	Fair.
19	7	0	52	55	30,11	56		NE	1	Fair.
	3	0	62	64	30,09	55		E	1	Fine.
20	7	0	51	59	30,03	65		N	1	Cloudy.
	3	0	62	66	29,99	51		SE	1	Fair.
21	7	0	48	59	29,92	63		NNE	1	Fair.
	3	0	58	64	29,84	59		SE	1	Fine.
22	7	0	50	57	29,78	60		N	1	Cloudy.
	3	0	52	58	29,75	54		N	1	Cloudy.
23	7	0	42	55	29,67	64		N	1	Cloudy.
	3	0	53	58	29,59	54		NW	1	Cloudy.
24	7	0	43	54	29,57	70		W	1	Rain.
	3	0	46	50	29,56	73		N	1	Rain.
25	7	0	44	54	29,63	74		N	1	Cloudy.
	3	0	46	56	29,75	63		N	1	Cloudy.
26	7	0	46	54	29,93	60		W	1	Fine.
	3	0	51	57	29,95	54		SW	1	Cloudy.
27	7	0	47	55	29,92	66		E	1	Cloudy.
	3	0	56	59	29,85	56		SE	1	Fair.
28	7	0	49	56	29,74	70		N	1	Fine.
	3	0	62	62	29,66	55		S	1	Fine.
29	7	0	58	58	29,73	61		N	1	Fine.
	3	0	63	61	29,78	53		N	1	Fine.
30	7	0	52	58	30,04	63		W	1	Fine.
	3	0	61	61	30,09	54		NE	1	Cloudy.
31	7	0	54	59	30,09	65		S	1	Cloudy.
	3	0	62	61	30,06	53		W	1	Cloudy.

Rain this Month 1,779 Inches.

METEOROLOGICAL JOURNAL

for June, 1814.

1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Winds. Str.	Weather.
June 1	7	0	50	58	30,05	67	E	1	Cloudy and hazy.
	3	0	55	59	29,99	64	E	1	Cloudy.
2	7	0	52	58	29,86	75	E	1	Rain.
	3	0	56	58	29,85	75	NNE	1	Cloudy.
3	7	0	52	58	29,84	73	E	1	Cloudy.
	3	0	54	58	29,76	78	E	1	Rain.
4	7	0	51	57	29,75	76	E	1	Rain.
	3	0	52	57	29,80	72	NE	1	Cloudy.
5	7	0	50	56	29,98	71	N	1	Cloudy.
	3	0	51	56	30,09	68	N	1	Cloudy.
6	7	0	49	55	30,13	65	E	1	Cloudy.
	3	0	56	55	30,13	62	E	1	Cloudy.
7	7	0	47	54	30,07	65	NE	1	Cloudy.
	3	0	51	55	30,05	60	E	1	Cloudy.
8	7	0	47	54	29,98	67	N	1	Cloudy.
	3	0	59	59	29,98	51	NE	1	Cloudy.
9	7	0	49	55	30,04	70	N	1	Fine.
	3	0	58	62	30,09	54	E	1	Fair.
10	7	0	50	57	30,11	68	E	1	Cloudy.
	3	0	59	62	30,12	56	E	1	Fine.
11	7	0	53	58	30,05	68	E	1	Cloudy.
	3	0	61	63	30,01	57	E	1	Cloudy.
12	7	0	54	58	29,80	72	E	1	Cloudy.
	3	0	65	63	29,84	61	NW	1	Cloudy.
13	7	0	54	59	30,02	70	E	1	Cloudy.
	3	0	64	61	30,05	64	E	1	Cloudy.
14	7	0	64	61	30,11	71	W	1	Cloudy.
	3	0	73	65	30,09	58	W	1	Fine. [the night.
15	7	0	64	64	29,92	79	S	1	Cloudy. A thunder storm in
	3	0	68	68	29,88	67	S	1	Fine.
16	7	0	59	62	29,99	66	W	1	Cloudy.
	3	0	64	65	29,96	66	SW	1	Cloudy.

Rain this Month 1,558 Inches.

METEOROLOGICAL JOURNAL

for June, 1814.

1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Winds. Str.	Weather.
June 17	7	0	54	61	30,10	66	NW	1	Fine.
	3	0	62	62	30,11	59	NW	1	Cloudy.
18	7	0	56	61	30,13	64	W	1	Cloudy.
	3	0	62	61	30,00	66	W	1	Cloudy.
19	7	0	57	61	29,92	76	W	1	Rain.
	3	0	63	62	29,82	63	NNW	1	Cloudy.
20	7	0	52	59	29,83	62	N	1	Cloudy.
	3	0	59	59	29,79	63	N	1	Cloudy.
21	7	0	53	58	29,74	63	N	1	Cloudy.
	3	0	59	60	29,80	57	N	1	Cloudy.
22	7	0	53	58	29,90	70	N	1	Cloudy.
	3	0	55	59	29,97	70	E	1	Rain.
23	7	0	52	57	30,10	71	N	1	Cloudy.
	3	0	57	59	30,17	65	NNE	1	Cloudy.
24	7	0	52	57	30,25	68	N	1	Cloudy.
	3	0	57	58	30,32	65	N	1	Cloudy.
25	7	0	53	57	30,33	64	N	1	Cloudy.
	3	0	57	58	30,28	64	N	1	Cloudy.
26	7	0	53	57	30,12	65	N	1	Cloudy.
	3	0	58	58	30,08	63	NNE	1	Cloudy.
27	7	0	53	57	30,08	68	N	1	Cloudy.
	3	0	58	58	30,08	62	N	1	Cloudy.
28	7	0	56	57	30,02	69	NW	1	Cloudy.
	3	0	63	60	29,97	61	N	1	Cloudy.
29	7	0	54	58	29,91	71	SSE	1	Hazy.
	3	0	67	60	29,90	59	NW	1	Cloudy.
30	7	0	60	60	29,91	67	N	1	Cloudy.
	3	0	64	66	29,94	56	N	1	Fine.

Rain this Month 1,558 Inches.

METEOROLOGICAL JOURNAL

for July 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Str.	Weather.
July 1	7	0	59	61	29,91	62	W	1	Cloudy.
	3	0	63	62	29,89	59	N	1	Cloudy.
2	7	0	56	60	29,98	61	N	1	Fine.
	3	0	64	66	30,02	55	W	1	Fair.
3	7	0	60	61	30,03	61	SW	1	Fine.
	3	0	68	65	30,02	55	NW	1	Cloudy.
4	7	0	59	62	30,05	65	W	1	Fine.
	3	0	67	64	30,05	56	W	1	Cloudy.
5	7	0	61	63	30,03	75	W	1	Cloudy.
	3	0	72	68	30,04	56	NW	1	Cloudy.
6	7	0	58	63	30,07	67	W	1	Cloudy.
	3	0	70	71	30,05	57	W	1	Fine.
7	7	0	58	63	29,97	66	S	1	Fair.
	3	0	71	71	29,90	58	W	1	Cloudy.
8	7	0	60	66	29,92	68	W	1	Cloudy.
	3	0	65	66	29,87	69	SW	1,2	Rain.
9	7	0	61	65	29,78	73	SW	1	Cloudy.
	3	0	64	66	29,77	68	SW	1	Cloudy.
10	7	0	61	65	29,75	71	S	1	Cloudy.
	3	0	64	64	29,75	69	W	1	Cloudy.
11	7	0	58	62	29,91	68	SW	1	Fine.
	3	0	65	65	29,95	62	W	1	Fine.
12	7	0	57	63	30,10	65	W	1	Fine.
	3	0	66	65	30,12	57	NNE	1	Cloudy.
13	7	0	60	64	30,14	64	W	1	Cloudy.
	3	0	62	64	29,99	58	W	1	Cloudy.
14	7	0	55	62	29,87	65	W	1	Fine.
	3	0	63	64	29,82	59	W	1	Cloudy.
15	7	0	57	62	29,79	65	NW	1	Cloudy.
	3	0	63	63	29,76	63	W	1	Cloudy and hazy.
16	7	0	58	62	29,70	70	N	1	Cloudy.
	3	0	63	63	29,79	65	E	1	Cloudy.

Rain this Month 0,676 Inches.

METEOROLOGICAL JOURNAL
for July 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Str.	Weather.
July 17	7	0	54	61	29.94	70	E	1	Cloudy.
	3	0	64	65	29.96	62	SW	1	Cloudy.
18	7	0	57	62	29.95	70	W	1	Cloudy.
	3	0	67	65	29.92	64	S	1	Cloudy.
19	7	0	58	62	29.93	68	W	1	Cloudy.
	3	0	67	65	29.88	60	W	1,2	Cloudy.
20	7	0	61	63	29.73	69	S	2	Cloudy.
	3	0	67	65	29.67	61	S	2	Cloudy.
21	7	0	59	63	29.77	69	W	1	Fair.
	3	0	69	67	29.85	56	E	1	Cloudy.
22	7	0	61	64	29.95	65	E	1	Fine.
	3	0	67	66	30.27	56			
23	7	0	58	64	30.27	68	W	1	Fair.
	3	0	71	71	30.27	60	S	1	Fine.
24	7	0	56	66	30.23	65	SE	1	Fair.
	3	0	72	76	30.11	60	E	1	Fair.
25	7	0	65	67	29.94	67	E	1	Fine.
	3	0	74	75	29.85	56	SSE	1	Fine.
26	7	0	64	69	29.87	67	W	1	Fine.
	3	0	73	76	29.90	58	W	1	Cloudy.
27	7	0	65	70	30.04	67	ENE	1	Fine.
	3	0	76	77	30.03	59	E	1	Fine.
28	7	0	70	71	29.94	70	E	1	Fair.
	3	0	79	81	29.89	55	SE	1	Cloudy.
29	7	0	66	74	29.80	67	W	1	Cloudy.
	3	0	71	75	29.86	57	W	1,2	Cloudy.
30	7	0	61	69	30.01	68	W	1	Fine.
	3	0	71	74	30.07	56	W	1,2	Fine.
31	7	0	62	69	30.11	64	W	1	Fine.
	3	0	73	73	30.04	56	W	1	Fine.

Rain this Month 0.676 Inches.

METEOROLOGICAL JOURNAL
for August, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Rain this Month 2,000 Inches.	Winds. Points.	Str.	Weather.
Aug. 1	7	0	63	69	29,92	64		NW	1	Cloudy.
	3	0	72	74	29,91	57		NW	1	Fine.
2	7	0	62	67	30,08	66		W	1	Fine.
	3	0	71	73	30,11	60		SW	1	Fine.
3	7	0	60	69	30,06	68		W	1	Fair.
	3	0	72	73	29,96	57		SW	1	Cloudy.
4	7	0	56	67	30,12	66		W	1	Fair.
	3	0	69	71	30,12	57		WSW	1	Fair.
5	7	0	60	66	29,88	66		S	1	Fine.
	3	0	68	70	29,79	61		SW	1	Fine.
6	7	0	59	66	29,75	66		W	1	Cloudy.
	3	0	68	70	29,87	58		NNW	1	Fine.
7	7	0	58	66	30,03	66		W	1	Cloudy.
	3	0	67	68	29,97	59		W	1,2	Cloudy.
8	7	0	58	65	29,73	70		N	1	Cloudy.
	3	0	66	67	29,71	60		W	2	Cloudy.
9	7	0	56	64	29,92	64		W	1	Fine.
	3	0	65	68	30,02	55		NW	1	Cloudy.
10	7	0	58	64	30,05	68		W by N	1	Cloudy.
	3	0	65	66	30,05	60		NW	1	Cloudy.
11	7	0	60	64	30,18	66		NW	1	Cloudy.
	3	0	67	65	30,15	57		W	1	Cloudy.
12	7	0	57	64	30,14	70		W	1	Cloudy.
	3	0	68	66	30,11	64		W	1	Cloudy.
13	7	0	59	64	29,99	68		SW	1,2	Cloudy.
	3	0	66	66	29,89	63		SW	1,2	Cloudy.
14	7	0	55	63	29,88	66		N N W	1	Fair.
	3	0	65	68	29,86	52		W	1	Fine.
15	7	0	53	62	29,91	65		W	1	Fair.
	3	0	65	65	29,92	50		W	1	Cloudy.
16	7	0	59	63	29,87	71		S	1	Rain.
	3	0	61	64	29,81	59		NW	1	Cloudy.

METEOROLOGICAL JOURNAL
for August, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Rain this Month 2,000 Inches.	Winds. Points.	Str.	Weather.
Aug. 17	7	0	54	61	29,93	68		W	1	Fair.
	3	0	65	64	29,99	56		WNW	1	Fine.
18	7	0	62	63	30,02	69		W	1	Cloudy.
	3	0	68	66	30,05	57		W	1	Cloudy.
19	7	0	59	64	30,06	60		W	1	Cloudy and hazy.
	3	0	63	63	29,99	56		NNW	1	Cloudy.
20	7	0	52	61	30,00	66		W	1	Fine.
	3	0	60	63	30,03	62			1	Cloudy.
21	7	0	56	62	29,98	66		S	1	Cloudy.
	3	0	63	63	29,89	68		S	2	Cloudy.
22	7	0	58	63	29,87	69		W	1	Cloudy.
	3	0	66	68	29,89	59		SW	1	Fine.
23	7	0	63	64	29,74	73		E	1	Fine.
	3	0	70	66	29,67	58		S	1	Cloudy.
24	7	0	58	64	29,67	69		E	1	Cloudy.
	3	0	60	64	29,55	77		NE	1	Rain.
25	7	0	58	63	29,64	77		S	1	Cloudy.
	3	0	62	65	29,66	65		NNW	1	Rain.
26	7	0	58	61	29,79	68		W	1	Fine.
	3	0	63	67	29,84	57		NNW	1	Fine.
27	7	0	51	62	29,94	68		W	1	Hazy.
	3	0	61	66	29,97	56		N	1	Fine.
28	7	0	51	61	29,99	68		NNW	1	Fair.
	3	0	61	66	30,05	55		E	1	Fine.
29	7	0	52	60	30,07	64		N	1	Fair.
	3	0	65	68	30,17	54		W	1	Fair.
30	7	0	57	63	30,22	69		W	1	Cloudy.
	3	0	65	68	30,21	59		WNW	1	Cloudy.
31	7	0	61	65	30,29	70		W	1	Cloudy.
	3	0	69	67	30,30	64		N	1	Cloudy.

METEOROLOGICAL JOURNAL
for September, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °		Winds. Points.	Str.	Weather.
Sep. 1	7	30	60	64	30,36	69		E	1	Fine.
	3	0	65	67	30,37	59		E	1	Fine.
2	7	30	58	63	30,32	66		NW	1	Fine.
	3	0	63	70	30,27	60		E	1	Fair.
3	7	30	57	64	30,24	68		N	1	Cloudy and thick.
	3	0	63	65	30,23	60		N	1	Cloudy.
4	7	30	52	61	30,31	64		N	1	Fair.
	3	0	61	64	30,26	58		E	1	Cloudy.
5	7	30	52	61	30,23	64		N	1	Fair.
	3	0	61	64	30,21	55		NW	1	Cloudy.
6	7	30	54	62	30,18	66		W	1	Cloudy.
	3	0	64	65	30,07	57		W	1	Cloudy.
7	7	30	53	61	29,81	68		W	1	Cloudy.
	3	0	55	62	29,78	65		NNE	1	Rain.
8	7	30	56	61	29,99	72		NE	1	Cloudy.
	3	0	60	62	30,10	61		N	1	Cloudy.
9	7	30	54	60	30,14	70		N	1	Cloudy.
	3	0	61	65	30,15	59		N	1	Fine.
10	7	30	54	61	30,15	65		N	1	Fine.
	3	0	58	62	30,15	58		NE	1	Cloudy.
11	7	30	48	59	30,15	66		N	1	Fair.
	3	0	60	65	30,17	57		N	1	Fine.
12	7	30	49	59	30,25	65		E	1	Cloudy.
	3	0	57	61	30,23	58		N	1	Cloudy.
13	7	30	44	58	30,23	66		SW	1	Fine, rather hazy.
	3	0	57	61	30,20	59		N	1	Cloudy.
14	7	30	44	57	30,21	68		W	1	Thick and hazy.
	3	0	58	61	30,22	59		E	1	Cloudy.
15	7	30	49	58	30,22	68		NE	1	Hazy.
	3	0	60	65	30,17	61		E	1	Fine.
16	7	30	50	59	30,13	71		N	1	Fine, rather hazy.
	3	0	60	60	30,10	71		N	1	Hazy.

Rain this Month 0,905 Inches.

METEOROLOGICAL JOURNAL

for September, 1814.

1814	Time. H.	Time. M.	Therm. without.	Therm. within.	Barom.	Hygrometer.		Winds. Points.	Winds. Str.	Weather.
			o	o	Inches.					
Sep. 17	7	30	52	60	30,09	71		NE	1	Hazy.
	3	0	62	66	30,08	55		S	1	Fair.
18	7	30	56	61	30,12	66		E	1	Hazy.
	3	0	62	67	30,16	67		NE	1	Hazy.
19	7	30	53	58	30,16	68		NNE	1	Cloudy and hazy.
	3	0	64	72	30,13	55		S	1	Fair.
20	7	30	57	64	30,08	63		S	1	Fine.
	3	0	67	71	30,02	56		S	1	Fine.
21	7	30	59	66	29,89	71		S	2	Cloudy.
	3	0	63	66	29,83	62		S	1,2	Cloudy.
22	7	30	54	63	29,83	69		W	1	Cloudy.
	3	0	61	65	29,82	63		W	1	Cloudy.
23	7	30	56	62	29,98	70		S	1	Fine.
	3	0	58	63	29,90	71		S	1	Rain.
24	7	30	63	65	29,80	72		S	2	Rain.
	3	0	65	65	29,65	78		S	1	Fine.
25	7	30	62	64	29,70	70		SW	1	Rain.
	3	0	63	64	29,55	77		SW	1	Fine.
26	7	30	61	63	29,80	63		SE	1	Fine.
	3	0	60	62	29,85	68		SE	1	Fine.
27	7	30	58	62	29,80	66		W	1	Rain.
	3	0	59	63	29,75	72		W	1	Cloudy.
28	7	30	55	61	29,85	62		N	1	Fine.
	3	0	58	62	29,85	70		N	1	Fine.
29	7	30	57	62	29,95	64		N	1	Fine.
	3	0	55	61	30,00	69		N	1	Fine.
30	7	30	59	60	30,00	70		NE	1	Fine.
	3	0	58	61	30,05	68		NE	1	Fine.

Rain this Month 0,965 Inches.

METEOROLOGICAL JOURNAL

for October, 1814.

1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Winds. Str.	Weather.
Oct. 1	7	30	54	60	30,05	68	NE	2	Fine.
	3	0	55	59	30,10	62	NE	1	Fine.
2	7	30	52	60	30,15	61	NE	2	Fine.
	3	0	60	57	30,15	60	NE	1	Fine.
3	7	30	56	61	30,10	60	NE	1	Fine.
	3	0	52	56	30,15	76	NE	1	Fine.
4	7	30	58	58	30,20	66	NE	1	Fine.
	3	0	54	57	30,15	67	NE	1	Fine.
5	7	30	46	54	30,13	70	NNE	1	Hazy.
	3	0	55	61	30,05	60	SE	1	Fair.
6	7	30	40	53	29,88	70	W	1	Cloudy and hazy.
	3	0	55	57	29,78	62	W	1,2	Cloudy.
7	7	30	43	54	29,80	70	W	1	Fine, rather hazy.
	3	0	51	57	29,84	60	N	1	Cloudy.
8	7	30	42	52	29,90	65	NW	1	Fine.
	3	0	51	56	29,94	61	W	1	Fine, rather hazy.
9	7	30	41	51	30,12	64	NNE	1	Fine.
	3	0	48	55	30,13	60	N	1	Cloudy.
10	7	30	34	50	30,22	65	W	1	Fine, rather hazy.
	3	0	45	53	30,19	57	SW	1	Fine.
11	7	30	46	51	29,99	65	S	1	Cloudy.
	3	0	52	52	29,89	63	W	1	Cloudy.
12	7	30	48	51	29,75	66	SSE	1	Cloudy.
	3	0	54	53	29,71	65	SSE	1	Cloudy.
13	7	30	55	53	29,63	69	S	1	Fine.
	3	0	58	58	29,61	66	SE	1	Cloudy.
14	7	30	55	55	29,48	73	SSE	1	Cloudy.
	3	0	60	59	29,42	62	SE	1,2	Cloudy.
15	7	30	50	57	29,54	72	W	1	Fine.
	3	0	58	59	29,54	70	W	1	Fine.
16	7	30	46	55	29,57	69	W	1	Fine.
	3	0	54	59	29,73	59	W	1	Cloudy.

Rain this Month 1,611 Inches.

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1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer.	Winds. Points.	Str.	Weather.
Oct. 17	7	30	47	55	29,77	69	W	1	Cloudy.
	3	0	55	58	29,70	66	SW	1	Cloudy.
18	7	30	53	56	29,40	72	S	2	Cloudy.
	3	0	52	58	29,26	73	W	1	Rain.
19	7	30	46	55	29,22	70	E	1,2	Cloudy.
	3	0	52	58	29,20	69	S	2	Rain.
20	7	30	43	55	29,27	72	NW	1	Fine.
	3	0	52	57	29,43	63	W	1	Cloudy.
21	7	30	39	53	29,74	71	W	1	Fine.
	3	0	52	58	29,88	66	W	1	Cloudy.
22	7	30	52	55	29,80	76	W	1	Cloudy.
	3	0	55	60	29,78	65	W	1	Cloudy.
23	7	30	50	56	29,62	66	NW	1	Fine.
	3	0	50	57	29,62	61	W	1	Fine.
24	7	30	41	53	29,83	69	W	1	Fine.
	3	0	49	58	29,83	61	W	1	Cloudy.
25	7	30	46	55	29,13	74	W	1	Rain. Wind and rain in the night.
	3	0	50	56	29,15	64	W	1	Cloudy.
26	7	30	41	52	29,54	72	NE	1	Cloudy.
	3	0	48	56	29,66	70	N	1	Cloudy.
27	7	30	44	53	29,80	74	N	1	Cloudy.
	3	0	49	54	29,82	70	W	1	Cloudy.
28	7	30	42	52	29,88	72	SW	1	Fine, rather hazy.
	3	0	51	54	29,88	65	S	1	Cloudy.
29	7	30	45	52	29,82	74	E	1	Foggy.
	3	0	50	52	29,73	75	E	1	Rain.
30	7	30	43	52	29,90	73	W	1	Hazy.
	3	0	48	53	29,93	70	E	1	Cloudy.
31	7	30	46	52	29,95	75	N	1	Cloudy.
	3	0	53	53	29,94	70	E	1,2	Cloudy.

Rain this Month 1,611 Inches.

METEOROLOGICAL JOURNAL

for November, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Str.	Weather.
Nov. 1	8	0	48	52	29,99	73	N	1	Thick and hazy.
	3	0	48	52	29,98	72	N	1	Cloudy.
2	8	0	44	52	30,00	70	N	1	Cloudy.
	3	0	43	52	30,02	68	N	1	Cloudy.
3	8	0	40	50	29,99	69	N	1	Cloudy.
	3	0	46	52	29,84	66	N	1	Cloudy.
4	8	0	38	49	29,89	74	N	1	Foggy.
	3	0	43	50	29,88	70	N	1	Cloudy.
5	8	0	41	49	29,85	73	N	1	Cloudy.
	3	0	44	51	29,78	75	N	1	Rain.
6	8	0	36	49	29,85	75	W	1	Thick fog.
	3	0	43	49	29,88	71	N	1	Fair.
7	8	0	40	47	29,81	73	W	1	Fine.
	3	0	48	49	29,65	69	W	1	Cloudy.
8	8	0	37	48	29,37	72	W	1	Fine.
	3	0	40	48	29,32	70	W	1	Fine.
9	8	0	36	47	29,44	69	W	1	Fine, rather hazy.
	3	0	42	48	29,47	66	W	1	Rain.
10	8	0	33	44	29,98	65	NNW	1	Hazy.
	3	0	40	51	30,18	63	NW	1	Fine.
11	8	0	34	46	30,31	71	W	1	Hazy.
	3	0	43	50	30,25	65	W	1	Cloudy.
12	8	0	48	52	29,85	74	W	1	Rain.
	3	0	49	53	29,90	62	NW	1	Fine.
13	8	0	44	50	29,89	72	W	1	Fine.
	3	0	46	51	29,89	65	NW	1	Cloudy.
14	8	0	45	50	29,87	76	W	1	Cloudy.
	3	0	52	55	29,81	74	W	1	Cloudy.
15	8	0	48	54	29,91	75	SW	1	Cloudy.
	3	0	50	56	29,87	72	NW	1	Cloudy.
16	8	0	47	52	29,35	74	S	2,3	Rain.
	3	0	48	55	29,69	65	NW	2	Fine.

Rain this Month 1,864 Inches.

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1814	Time. H.	Time. M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Rain this Month 1,864 Inches.	Winds. Points.	Winds. Str.	Weather.
Nov. 17	8	0	43	51	30,06	73		W	1	Fine.
	3	0	53	56	29,95	75		SW	1	Fine.
18	8	0	48	54	29,91	73		SW	1	Cloudy.
	3	0	50	57	29,73	67		S	2	Cloudy.
19	8	0	45	54	29,43	73		W	1	Cloudy.
	3	0	46	58	29,49	66		NW	1	Cloudy.
20	8	0	39	53	29,51	71		NW	1	Cloudy.
	3	0	40	53	29,60	74		NE	1	Cloudy.
21	8	0	37	51	29,62	71		NE	1	Fine.
	3	0	39	52	29,66	64		N	1	Fair.
22	8	0	28	46	29,71	69		W	1	Hazy.
	3	0	39	52	29,73	68		NW	1	Fair.
23	8	0	30	47	29,69	71		N	1	Foggy.
	3	0	38	51	29,70	72		E	1	Fine.
24	8	0	31	46	29,83	74		E	1	Thick and foggy.
	3	0	41	50	29,80	73		S	1	Cloudy.
25	8	0	46	49	29,55	77		S	1	Rain.
	3	0	50	53	29,48	78		S	1	Rain.
26	8	0	46	53	29,27	75		W	1	Cloudy.
	3	0	46	53	29,46	73		W	1	Fine.
27	8	0	39	49	29,64	71		W	1	Fine.
	3	0	44	50	29,54	69		W	1	Rain.
28	8	0	38	48	29,69	77		W	1	Hazy.
	3	0	45	51	29,56	76		SW	1	
29	8	0	44	49	29,48	75		W	1	Cloudy.
	3	0	46	54	29,46	74		W	1	Fine.
30	8	0	42	48	29,32	73		NW	1	Fine.
	3	0	43	53	29,17	71		N	1	Fine.

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for December, 1814.

1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °	Winds. Points.	Str.	Weather.
Dec. 1	8	0	38	49	29.48	73	NW	1	Cloudy.
	3	0	43	53	29.64	69	NW	1	Cloudy.
2	8	0	36	49	29.78	72	NW	1	Foggy.
	3	0	40	52	29.80	70	NW	1	Thick and hazy.
3	8	0	36	50	29.92	73	SE	1	Cloudy and foggy.
	3	0	35	48	29.88	75	E	1	Cloudy and foggy.
4	8	0	35	46	29.53	75	S	1	Cloudy.
	3	0	45	52	29.46	75	SW	1	Cloudy.
5	8	0	35	46	29.36	76	W	1	Hazy.
	3	0	46	52	29.70	73	N	1	Cloudy.
6	8	0	34	47	29.98	72	NE	1	Fine.
	3	0	39	50	30.07	70	NNW	1	Fine.
7	8	0	41	48	29.87	69	S	2	Rain.
	3	0	42	54	29.74	75	SW	1	Cloudy.
8	8	0	46	48	29.60	78	W	1,2	Cloudy.
	3	0	48	52	29.46	75	SW	2	Rain.
9	8	0	49	52	29.31	75	W	1	Cloudy.
	3	0	45	55	29.47	67	NW	1,2	Cloudy.
10	8	0	33	49	29.76	70	E	1	Cloudy.
	3	0	40	52	29.46	76	E	1,2	Rain.
11	8	0	49	52	29.44	75	W	1	Rain.
	3	0	51	53	29.58	78	W	1	Cloudy.
12	8	0	53	53	29.70	79	WSW	2	Cloudy.
	3	0	55	57	29.71	78	W	2	Cloudy.
13	8	0	53	56	29.58	73	W	2	Cloudy.
	3	0	53	58	29.55	72	W	2	Cloudy.
14	8	0	45	55	29.81	73	W	1	Fine.
	3	0	52	58	29.72	73	SW	2	Cloudy.
15	8	0	52	55	29.63	73	SW	1,2	Fine.
	3	0	53	58	29.66	69	NW	1	Fine.
16	8	0	54	58	29.47	77	S	2,3	Cloudy.
	3	0	50	58	29.56	65	NW	2	Cloudy.

Rain this Month 2.250 Inches.

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1814	Time. H.	M.	Therm. without. °	Therm. within. °	Barom. Inches.	Hygrometer. °		Points.	Str.	Weather.
Dec. 17	8	0	51	57	29,70	70		NW	2	Cloudy.
	3	0	52	57	29,84	75		W	2	Cloudy.
18	8	0	54	57	29,85	72		W	3	Cloudy.
	3	0	55	56	29,89	70		S	1,2	Cloudy.
19	8	0	53	56	29,73	73		W	2	Cloudy.
	3	0	53	58	29,73	71		W	1	Cloudy.
20	8	0	38	52	30,10	70		W	1	Fine rather hazy.
	3	0	42	56	30,11	69		NW	1,2	Fine.
21	8	0	38	48	30,03	68		E	1	Fine.
	3	0	39	53	29,92	67		E	1	Cloudy.
22	8	0	34	48	29,76	65		W	1	Fine.
	3	0	38	51	29,65	66		E	1,2	Cloudy.
23	8	0	35	47	29,48	68		E	1	Cloudy.
	3	0	38	50	29,61	66		N	1	Cloudy.
24	8	0	32	41	29,68	66		E	1	Cloudy.
	3	0	32	47	29,65	68		E	1	Cloudy.
25	8	0	31	44	29,62	71		SE	1	Cloudy.
	3	0	32	44	29,63	72		NW	1	Snow.
26	8	0	33	40	29,62	75		W	1	Rain much snow in the night.
	3	0	36	46	29,62	73		E	1	Cloudy.
27	8	0	34	43	29,48	76		E	1	Rain.
	3	0	38	47	29,24	78		S	1	Cloudy.
28	8	0	40	46	29,92	80		E	1	Rain.
	3	0	39	49	29,20	80		N	1,2	Cloudy.
29	8	0	36	45	29,71	72		W	1	Cloudy.
	3	0	38	49	29,76	73		E	1	Cloudy.
30	8	0	43	48	29,86	80		SW	1	Cloudy.
	3	0	47	50	29,81	80		S	1	Rain.
31	8	0	37	48	29,94	77		W	1	Fine.
	3	0	44	52	30,04	75		W	1	Fair.

Rain this Month 0,801 Inches.

1814.	Thermometer without.			Thermometer within.			Barometer.*			Hygrometer.			Rain.†
	Greatest height.	Least height.	Mean height.	Greatest height.	Least height.	Mean height.	Greatest height.	Least height.	Mean height.	Greatest height.	Least height.	Mean height.	
	Deg.	Deg.	Deg.	Deg.	Deg.	Deg.	Inches.	Inches.	Inches.	Deg.	Deg.	Deg.	Inches.
January	40	17	28,8	47	29	38,5	30,20	28,32	29,53	80	62	73,2	1,122
February	48	23	35,6	55	41	46,7	30,46	29,38	30,06	78	61	69,6	0,528
March	54	29	37,5	58	39	45,9	30,39	28,80	29,73	79	63	71,5	0,718
April	64	43	50,8	67	51	57,3	30,26	29,32	29,84	77	45	64,1	1,296
May	63	43	51,8	66	53	57,3	30,46	29,41	29,96	77	51	62,2	1,779
June	73	47	56,5	68	54	59,1	30,33	29,74	30,00	79	51	65,9	1,558
July	79	54	64,0	81	60	66,4	30,33	29,67	29,80	75	55	63,3	0,676
August	72	51	61,6	76	60	65,5	30,30	29,55	29,96	77	52	63,4	2,000
September	65	44	57,5	72	57	62,7	30,37	29,55	30,05	78	55	65,1	0,965
October	60	34	49,5	61	50	55,3	30,22	29,13	29,78	76	57	65,6	1,611
November	53	28	42,7	58	44	50,9	30,31	29,17	29,73	78	62	72,1	1,864
December	55	32	42,6	58	40	51,0	30,11	29,20	29,65	80	65	72,7	2,250
Whole year			48,2			54,7			29,84			67,3	16,367

* The quicksilver in the bason of the barometer, is 81 feet above the level of low water spring tides at Somerset-house.

† The Society's Rain Gage is 114 feet above the same level, and 75 feet 6 inches above the surrounding ground.

By another Rain Gage placed at a few feet distant from the former and 11 feet 6 inches lower, the quantity of rain this year appears to have been 20,723 inches.

Mean Variation of the Magnetic Needle,

June, 1814,	24°	16′	42″ West.
July,	24	17	54
August	24	21	10
September	24	20	33